DELINEATIONS OF LANDTYPE ASSOCIATIONS WITHIN THE GREAT PLAINS PHYSIOGRAPHIC PROVINCE OF WYOMING

Bureau of Land Management/University of Wyoming
Contract K-910-P40261

1 March 1995

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FINAL REPORT

UNIVERSITY OF WYOMING

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1.0 OBJECTIVES OF THE WORK

1.1 Requirements of the Work Order

1.1.1 "The University of Wyoming, Department of Botany, will delineate landscape complexes (landtype associations sensu Bailey (1980) within the portion of the Great Plains Physiographic Province occurring in Wyoming in the counties listed under - location of work"

1.1.2 "The location of the work area is Crook, Weston, Niobrara, and Converse Counties, Wyoming"

1.1.3 "Delineations will be based on a combination of LANDSAT Thematic Mapper remotely sensed imagery; GIS (geographic information system) spatial data representing topography, geology, climate, soils and vegetative land cover; and aided by extant map delineations such as Bailey's ecoregions (Bailey 1980) and Hammond's physiographic land units."

1.1.4 "The landscape complexes will be provided in both paper map form and Arc/Info digital form. The scale, organization and other related items will be determined by the BLM."

1.1.5 Deliverables [will include]:

a) 25 copies of a written report with rationale for the delineations,
b) a preliminary map product within 5 months of the initiation of the agreement,
c) 3 sets of slides of the maps,
d) 3 sets of overlays for the overhead projector,
e) 3 large paper maps will be produced. Scale and content to be determined by the BLM.

In our own words, the objective of this work is to provide a scientifically based spatial framework for ecosystem management in the Great Plains Physiographic Province of Wyoming that incorporates ecological principles and processes across a range of scales.

2.0 PHILOSOPHY OF THE WORK

2.1 Concept of the "Ecosystem" in Terms of Ecosystem Management

This work is a continuation of related work with the Wyoming State Office of the BLM in which we delimited "ecosystem boundaries" for the Buffalo Resource Area (Reiners and Thurston 1994). In that report we discussed the concept of ecosystem management--the instigating mandate for this work--illustrating the imprecision of this concept with differing statements on what ecosystem management means. To provide similar context for this present report, it is worth expanding on some of the background statements we wrote in that proceeding report.

Traditionally, and even in most contemporary ecological research, the ecosystem concept carries a sense of homogeneity, and the real world is viewed as a mosaic of local-area ecosystems.

> "The most common use of ecosystem by ecologists is in a localized sense, referring to a distinct and coherent ecological community of organisms and the physical environment with which they interact" Slocombe (1993)

However, applied ecologists and land managers recognize that this local site usage is not necessarily the only or best usage in the context of ecosystem management. Recognizing that broader land units such as landscapes or regions can be treated as ecosystems, Slocombe suggests that a better concept of ecosystem is

> "the notion of a bounded, self-maintaining system of varied, living and nonliving, interacting parts."

This definition is hardly more helpful but the intent is to accept more internal heterogeneity in the ecosystem definition and to maintain the basic idea interactions, including interactions between different local-area ecosystems in a larger spatial context.

Among the most satisfactory statements on ecosystem management are those based on personal communication with Prof. D.H. Knight. Knight lists these working rules:

"- focus on larger areas,

- consider boundary effects,

- consider effects of landscape change,

- realize that changes occur regardless of management,

- take a long-term perspective,

- predict cumulative effects,

- monitor key variables,

- manage for sustainability, and

- practice integrated planning."

If we adopt the rules Knight (and others) suggest, then "management unit ecosystems" are, by definition, going to be larger than the conventional, site-level ecosystem. Knight says that management unit ecosystems involve landscapes, which in turn, represent the aggregation of related terrain units, each bearing one or more kinds of site-level ecosystems on them. This makes sense to us and we conclude that land management ecosystems will be relatively large, incorporating at least one landscape, to be defined and discussed below.

2.2 Concept of the Landscape

Like "ecosystem," "landscape" is an abstraction--a human construct--and has no absolute definition that automatically imposes boundaries on real terrain. Like ecosystems, landscapes can be studied at different spatial and temporal scales. Forman and Godron (1986) define landscape as:

> "a heterogeneous land area composed of a cluster of interacting components that is repeated in a similar format throughout."

We suggest that this definition is weakened by the use of the term "cluster" which implies a three-dimensional aggregation (e.g. "cluster of grapes"). With substitution of the term "mosaic," for a two-dimensional array, for "cluster," this definition is a reasonable, if abstract, definition of landscape.

Elaborating on these "components" Forman and Godron (1986) discuss characteristics typically repeating across land areas:

> "1) a cluster of ecosystem types, 2) the flows or interactions among the ecosystems of such a cluster, 3) the geomorphology and climate, 4) the set of disturbance regimes, and 5) the relative abundance of ecosystems in such a cluster." (from Risser 1987)

We draw particular attention to item three in that series--geomorphology and climate. We will argue later that the principal determinant we have to use in order to define a landscape in tangible terms, that is, as mapped land units on the ground, will be topography, determined, at this scale, mainly by geomorphological properties of the terrain. Climate is one of the determinants of geomorphology but macroclimate, at least, is more generally expressed over a larger area and thus is not usually unique to a particular landscape.

Turner and Gardner (1991) have defined "landscape" slightly differently:

> "Landscape commonly refers to the landforms of a region in the aggregate...or to the land surface and its associated habitats at scales of hectares to many square kilometers. Most simply, a landscape can be

considered to be a spatially heterogeneous area."

These authors discuss ecology in the landscape context ("landscape ecology") and define various dimensions of that subject. Of interest to this report is a brief listing of landscape properties by those authors.

> "Three landscape characteristics that are especially useful to consider are structure, function and change... Structure refers to the spatial relationships between distinctive ecosystems, that is, the distribution of energy, materials and species in relation to the sizes, shapes, numbers, kinds, and configurations of components. Function refers to the interactions between the spatial elements, that is, the flow of energy, materials, and organisms among the component ecosystems. Change refers to alteration in the structure and function of the ecological mosaic through time."

Structure, function and change parallel properties listed by Forman and Godron (1986) but are still relatively abstract terms. What do they mean to land managers? Meaning has to be given to "structure," "function" and "change" by managers who are charged with evaluating and prescribing practices for a real piece of terrain.

More recently, an Federal interagency committee pertinent to this work order (ECOMAP) has defined landscape as:

> "a heterogeneous land area composed of a cluster of interacting ecosystems that is repeated in a similar form throughout; and can be viewed at one time from one place (adapted from Forman and Godron, and Webster)." (ECOMAP 1993)

This definition is essentially the same as that quoted above from Forman and Godron, except for the proviso that a landscape can be viewed at one time from one place. This is a curious clause in that the viewing range depends on the position of the viewer which could extend from the bottom of a gully to a satellite platform. In our opinion, this definition has the weakness of the original Forman and Godron definition and is compromised still further by the ambiguity of viewing position.

2.3 Concept of Land Management According to Sound Ecological Principles

What is the relationship between "ecosystem," "ecosystem management," and "landscape?" We suggest that the landscape concept, though abstract, may be a critical interface between "ecosystem" and "management."

We suggest that the concept of "landscape" carries with it connotations meant by "ecosystem management." Landscapes, by definition, consist of heterogeneous terrain and incorporate the notion of spatial interactions, and complex change over space with time--vital considerations for "ecosystem management." On one hand, the landscape can take on the definition of a special kind of ecosystem, on the other hand, we recognize that a landscape can be decomposed into a mosaic of what are normally considered more homogeneous "ecosystems."

While the concept of a landscape-ecosystem seems entirely congruent with concepts of ecosystem management, the problem of defining actual landscapes on real terrain still remains. We suggest that there are two, complementary resolutions to this problem.

The first resolution is acceptance at the outset that landscape-ecosystems can range in scale from hectares to many square kilometers. Different scales are appropriate for different issues. ECOMAP (1993) explicitly recognizes this in adopting a hierarchical framework for different levels of planning and analysis. Corollary to this view is the fact that smaller landscapes can be nested within larger ones. Still to be determined is a practical scale, or nesting level, for a particular environment. Surely, practical operational scales would be less in fine-grained, high relief terrain characteristic of well-dissected mountains, than in broadly sweeping plains.

The second resolution of this problem is recognition that landscape-ecosystems can and must be defined in terms of the phenomenon, criterion, or management issue at hand. If the issue is water quality, then watershed boundaries make fine landscape delineations. If the issue is wildlife habitat, then other terrain configurations relevant to the forage, water and cover requirements of wildlife become fundamental to landscape definition. In other words, definition of landscape-ecosystems is at some operational level situational. From this, it follows that landscape-ecosystems cannot be defined a priori for all circumstances. However, it is reasonable that terrain units having similar environmental features can represent units having similar kinds of landscape-ecosystems definable on a situational basis.

The goal of this work is to map terrain features having similar terrain configuration, ecological properties and management implications within which situational landscape-ecosystems can logically and conveniently be defined. Within the formal structure of the ECOMAP (1993) national hierarchy of ecological units, we have mapped Landtype Associations. Landtype Associations are defined by ECOMAP (1993) as units at the "landscape scale" as follows:

> "groupings of Landtypes or subdivisions of Subsections based upon similarities in geomorphic process, geological rock types, soil complexes, stream types, lakes, wetlands, and series, subseries, or plant association vegetation communities. Repeatable patterns of soil complexes and plant communities are useful in delineating map units at this level. Names of Landtype Associations are often derived from geomorphic history and

vegetation community."

For our purposes in this mapping work, we view Landtype Associations as aggregates of similar landscapes, regardless of whatever criterion is used for landscape definition. Landtype Associations are relatively large units (100's to 1000's of acres) featuring predictably occurring terrain features. Diagnostic terrain features characteristic of Landtype Associations include the form, extent and nature of ridges, cliffs, rock outcrops, talus slopes, fans, stream channels and associated terraces, benches, ravines, etc. We expect that each of these terrain features may bear different ecosystem components in terms of plant, animal and microbial populations and functions, and can be viewed as local area ecosystems.

We believe that understanding the topographic and ecological character of individual Landtype Associations will be an initial step to effective subdivision of these into landscapes determined by defined management needs. For example, further subdivision might well be done at the level of first or second order watersheds in some cases, or encompass an entire ridge-escarpment unit in others. However defined, it is important that these landscape units will have recognizable structural, functional and temporally dynamic properties as outlined by Turner and Gardner (1991).

In deciding whether geographic features should be mapped as a Landtype Association, we have asked ourselves the practical question:

> **"would this feature be recognized by land users and managers in the field, and would they agree that it is sufficiently different from surrounding terrain that they would consider its management differently?"**

In mapping Landtype Associations, we have not mapped land units on the basis of where boundaries ought to be based on small scale (low resolution) climate or geology maps, but rather, where GIS data and our field reconnaissance indicate recognizable common terrain properties within the Association that are recognizably different from terrain outside of the Association.

In addition to mapping Landtype Associations, we have also mapped higher hierarchical levels of the National Hierarchy of Ecological Units for the defined map area (see section below). In this process, we have defined land units up to two hierarchical levels above Landtype Association. These definitions of higher hierarchical units conform with nationally accepted nomenclature but differ, in some cases, with respect to location.

3.0 RELATIONSHIP WITH ECOMAP

In the time since this contract was made between BLM and the University of Wyoming, a memorandum of agreement between the USDA Forest Service, DOI

Bureau of Land Management, National Biological Survey (Service), U.S. Geological Survey, Fish and Wildlife Service, and the Environmental Protection Agency has been signed for the purpose of developing a common ecological map of the United States. The structure for this mapping project is defined as a National Hierarchical Framework of Ecological Units and has been defined and discussed in a report with the same title and cited here as ECOMAP (1993).

This national hierarchical framework differs from the previous Hierarchical system (Bailey 1980) used in our report on our work with the Buffalo Resource Area. The basic units and some of their descriptors are given in Tables 1 and 2.

Table 1. Principal map unit design criteria of ecological units of the National Hierarchical Framework of Ecological Units (ECOMAP 1993).

ECOLOGICAL UNIT	PRINCIPAL MAP UNIT DESIGN CRITERIA[1]
Domain	• Broad climatic zones or groups (e.g., dry, humid, tropical).
Division	• Regional climatic types (Koppen 1931, Trewartha 1968). • Vegetational affinities (e.g., prairie or forest). • Soil Order
Province	• Dominant potential natural vegetation (Kuchler 1964). • Highlands or mountains with complex vertical climate-vegetation-soil zonation.
Section	• Geomorphic province, geologic age, stratigraphy, lithology. • Regional climatic data. • Phases of soil orders, suborders or great groups. • Potential natural vegetation. • Potential natural communities (PNC) (FSH 2090)
Subsection	• Geomorphic process, surficial geology, lithology. • Phases of soil orders, suborders or great groups. • Subregional climatic data. • PNC-formation or series.
Landtype Association	• Geomorphic process, geologic formation, surficial geology, and elevation. • Phases of soil subgroups, families, or series. • PNC-series, subseries, plant associations.
Landtype	• Landform and topography (elevation, aspect, slope gradient, and position). • Phases of soil subgroups, families, or series. • Rock type, geomorphic process. • PNC-plant associations.
Landtype Phase	• Phases of soil families or series. • Landform and slope position. • PNC-plant association or phases.

[1] It should be noted that the criteria listed are broad categories of environmental and landscape components. The actual classes of components chosen for designing map units depend on the objectives for the map.

TABLE 2. Map scale and polygon size of ecological units of the National Hierarchical Framework of Ecological Units (ECOMAP 1993).

ECOLOGICAL UNIT	MAP SCALE RANGE	GENERAL POLYGON SIZE
Domain	1:30,000,000 or smaller	1000,000's of square miles
Division	1:30,000,000 to 1:7,500,000	100,000's of square miles
Province	1:15,000,000 to 1:5,000,000	10,000's of square miles
Section	1:7,500,000 to 1:3,500,000	1,000's of square miles
Subsection	1:3,500,000 to 1:250,000	10's to low 1,000's of square miles
Landtype Association	1:250,000 to 1:60,000	100's to 1,000's of acres
Landtype	1:60,000 to 1:24,000	10's to 100's of acres
Landtype Phase	1:24,000 or larger	<100 acres

In addition to defining these map units, the ECOMAP project has defined land units for the United States down to the section level (McNab and Avers 1994). A map of units down to sectional level for our map area is shown in Fig. 1.

With the accelerated development of the ECOMAP project during the term of this project, we have attempted to bring our map unit definitions into conformance with the nomenclature and suggested scales of that project. We have created Section, Subsection and Landtype Associations for this work area in conformance with our understanding of the definitions provided by ECOMAP (1993). Whether or not our map delineations will be adopted by ECOMAP remains to be seen.

Operationally, the higher hierarchical levels of the ECOMAP framework are not very relevant to management concerns. Domains, and Divisions and Provinces are very large, often crossing state boundaries. It is at the Sectional level that delineations may begin to become important. Certainly, Subsections and especially Landtype Associations are at the critical scale of administrative guidelines for land management. It is mainly at these levels that we have produced the delineations described below.

4.0 METHODS

4.1 Data Used to Delineate Map Units

We created a series of GIS coverages in Arc/Info format that overlapped the four designated counties plus Campbell County so that we could work within a rectangular frame. In fact, we have extended the data coverages and our mapping a slight distance west of the Campbell and Converse County lines, and south of the Converse and Niobrara County lines to insure appropriate links with terrain units encountered beyond the official map area set by county lines.

Coverages used include the following:

1) Thematic Mapper data subsampled at 100 m pixel resolution derived from the Wyoming GAP Project (Fig. 2).

2) Geology based on a state-wide digital product from the U.S. Geological Survey based, in turn, on Love and Christiansen (1985) (Fig. 3).

3) A digital rendering of scoria distribution produced with Mr. Ed Heffern of the Wyoming State BLM in the Buffalo Resource Area Project (Fig. 4).

4) Digital elevation model (DEM) data in both 90 m and 30 m lattice form from U.S. Geological Survey (1990). 30 m data were provided by the BLM State Office but are only available for about 60 % of the map area. Elevation can be viewed directly, as elevational belts (Fig. 5), or in terms of degree of slope (Fig. 6), or as shaded relief (Fig. 7).

5) Mean annual precipitation for the map area has been prepared as contours of equal precipitation based on the algorithms provided by Daly et al. (1994) (Fig. 8).

6) Land cover (mostly vegetation types) based on the Wyoming GAP Project digital map now in a final draft (Fig. 9).

These coverages were used interactively to compare the information in each. For example, land cover was often, but not always an indication of a change in Landtype Association. As landscape configuration was our principal basis for defining Landtype Associations, relief was usually the final determinant of where delineations were finally digitized. Very often, geology underlies changes in landscape configuration although the geological boundaries usually do not exactly correspond with relief data, particularly where 30 m relief data are available. The rationales used for each map unit delineated are described in the discussions of those units.

A variety of statistics were calculated for the land units delineated in this project including statistics for area, elevation, annual precipitation, land cover, and geology. The areas of the delineated land units are given in Table 1 of the Appendix. The elevation statistics are presented in Table 2 of the Appendix and were calculated using 3 arc second data available from the USGS. When projected to the Universal Transverse Mercator projection (zone 13), the resulting cell size is approximately 98 meters. The mean, minimum, maximum, and standard deviation were determined within ARC/INFO for each unique land unit by considering all elevation points within the polygon or polygons that make up the unit. The mean and standard deviation were then used to calculate the coefficient of variation, which is defined as follows.

$$\text{Coefficient of Variation} = \frac{\text{Standard Deviation}}{\text{Mean}} \times 100 \quad [\%]$$

The annual precipitation statistics are shown in Table 3 of the Appendix and were calculated using data obtained from the EPA. These data had a cell size of 10 km in their original form, but when projected to the Universal Transverse Mercator projection (zone 13), the cell size increased slightly to 11.1 km. In order to calculate the statistics, a rectangular array of sample points was established. The distance between points was arbitrarily set to the cell size for the elevation data (approximately 98 meters). The precipitation data were then sampled at these points and the statistics (mean, minimum, maximum, and standard deviation) for each unique land unit were calculated by considering all the sample points occurring within the polygon or polygons that make up that unit. As before, the coefficient of variation for each land unit was then calculated from the mean and standard deviation. Because of the greater cell size for precipitation data as compared with elevation data, the numbers of independent estimates for polygons were actually less. For smaller polygons, the statistical estimates of precipitation must be regarded with caution.

In addition to the elevation and precipitation data associated with the various land units, the units were analyzed to determine the land cover types present in each land unit and the areas of these types. These data are presented in Table 4 of the Appendix. The areas are given in hectares and as a percent of the total area occupied by the land unit. The areas were determined by intersecting the land unit coverage and the land cover coverage to obtain a coverage that has polygons with the attributes of both input coverages. Thus, a particular land unit can be selected using the land unit coverage attributes and this unit analyzed to determine information about the land cover types using the land cover attributes. A similar analysis was also done for the geologic formations, with the results appearing in Table 6 of the Appendix.

4.2 Map Accuracy

There are many factors that affect the accuracy of the land unit delineations. The main source of error is judgement on our part as to what units should be mapped and how these units should be defined. A good example of this type of error is the delineation of the North Platte River Valley Landtype Association. Should quaternary alluvium from the geology coverage be used as the main determinant of the delineation? We chose not to use this criteria since 30 meter shaded relief revealed that the valley often diverged significantly from the alluvium delineation. Should the line be at the base of the valley walls or the top? We decided to map at the base because of the difficulty in placing a line at the top when the walls gradually rise away from the valley bottom and there is no distinct upper edge. What should be done when 30 meter DEM data are not available? We chose to digitize lines drawn on 1:100,000 topographic maps. For each map unit, there were a multitude of decisions to be made and this results in judgement error being the most significant source of error in the delineations. Someone else, using their best judgement, might come up with lines that, in places, deviate significantly from ours. The maximum deviation might be several kilometers or more.

A second source of error is the error associated with each coverage used. The main coverages from which delineations were made were the geology and DEM coverages. Although the errors associated with the geology coverage are not known, the coverage was digitized from 1:500,000 source materials and the digitizing error alone could be 100's of meters. When the DEM data are used in making delineations, it is the horizontal error which is significant. This error for the 90 m DEM data is 100 m, while the horizontal error for the 30 m DEM data is 15 m. As different coverages were used to make delineations of different map units, the error inherent in those coverages carries over to those particular map delineations.

A third source of map error is our own digitizing error. Many delineations were digitized on-screen with a variety of displays in the background. We often used shaded relief with hatched geology polygons over the relief. The display was zoomed until the individual pixels were clearly visible. When there were distinct features to follow, the lines drawn were within 1 to 2 pixels of their desired location (30-60 m with 30 m DEM data). In some cases, we digitized lines drawn on 1:100,000 paper maps. We strived to achieve RMS errors of 0.003 inches or less, but this is not always possible with paper maps, especially if they have been previously folded. In no case was the RMS error greater than 0.008 inches, which converts to 20.3 m on the ground at a scale of 1:100,000. This is a reasonable error when considering the other sources of error. Even though an RMS error is low, the actual digitizing error will always be greater unless the same care is used to digitize the lines as is used to digitize the registration points, which is generally not the case. We have found from past experience that deviations of up to 1 mm can be expected when comparing lines plotted from the digitized data with the corresponding lines on the source materials. This translates to 100 m at a 1:100,000 scale.

Since the accuracy associated with a given delineation depends on many factors and since these factors may vary for different parts of the delineation, it is difficult to specify one number that reflects the true accuracy situation. Lines based on distinct features visible in the 30 m shaded relief displays are going to be more accurate than lines based on 90 m data or lines base on the geology coverage. In an effort to document the source/criteria for a given delineation and to provide some sense of accuracy, the arcs in the ARC/INFO land unit coverage were attributed with a 3-digit source/criteria code. A list of these codes is presented in Table 8 of the Appendix. Codes ranging from 101 to 199 indicate lines obtained directly from other coverages. Codes from 201 to 299 indicate lines digitized on-screen with the specified background display. Codes from 301 to 399 are for lines digitized from paper maps.

In view of the uncertainties associated with the delineations, it is advisable to think of the lines as fuzzy lines with varying widths that depend on the many factors affecting accuracy. The position of these lines may very well change as judgement improves or better data become available.

4.3.Interactions with BLM Personnel

This work benefitted through frequent interaction and assistance by BLM personnel. Besides a number of telephone calls not recorded here, progress was reviewed at intervals with BLM, and in two cases, U.S. Forest Service personnel, at the following meetings.

3.3.1 20 Dec. 1994 meeting in Laramie with BLM personnel and U.S. Forest Service ecologist, Dr. Judy Van Ahlefeldt to review delineations and discuss the relationship of this work with ECOMAP activities.

3.3.2 Early Jan. 1995 meeting in Laramie with Bill Daniels and Jon Johnson to review new definitions of delineations and how this work should be related to ECOMAP activities.

3.3.3 26 Jan. 1995 meeting in Laramie with Bill Daniels and Jon Johnson to confer on progress and view slide illustrations available at the BLM office. A very preliminary sketch of Section and Subsectional delineations by Forest Service personnel in Denver on the preceding day had been provided for our consideration by Dr. Van Ahlefeldt.

3.3.4 4 Feb. 1995 aerial photo reconnaissance of the work area from Cheyenne, across the northeastern corner of the State, across to the Bighorn Mountains and back to Cheyenne by Jon Johnson (BLM) and Steve Ogle (representing Reiners and Thurston).

3.3.5 9 Feb. 1995 meeting in Cheyenne with the BLM State Director and Associate Director to review work and plan on further presentations.

3.3.6 23 Feb. 1995 travel by Bill Daniels, Jon Johnson, Bruce Keating, Robert Thurston and Bill Reiners to a joint regional BLM-USFS meeting in Lakewood, CO to present the mapping effort.

3.3.7 2 March 1995 presentation of the work before BLM personnel of the Casper District Office, Casper, Wyoming.

5.0 LAND AREA DELINEATIONS: RATIONALES AND DESCRIPTIONS

5.1 Overview

Table 3 presents the land units mapped in this work, together with our previous mapping work done in Sheridan, Johnson and Campbell Counties, based on the National Hierarchical Framework. In the process, we have recognized a unit named "Duck Creek Breaks" which partially falls within the Buffalo Resource Area (BRA) (our former mapping area) and thereby represents a change in our work for that area. We also wish to note that with the advent of 30 m data during this contract period, that the delineations for the Powder River Breaks and Scoria Hills Subsections could profitably be changed, mostly in expanding those units.

Table 3. Map delineations for Sheridan, Johnson, Campbell, Crook, Weston, Converse and Niobrara Counties based on the National Hierarchical Framework (ECOMAP 1993) to the sectional level. Numbers in parentheses in normal font are codes for map units from Bailey et al. (1994) and McNab and Avers (1994). Locational changes in positions of Sections are noted as *REDRAWN* in upper case and italics. Additions at lower hierarchical levels recognized and organized by us as well as codes we have assigned to them are printed in **bold type**.

I. Domain--Dry Domain (300)

A. Temperate Steppe Division (330)

1. Great Plains-Palouse-Dry Steppe Province (331)

a. Northwestern Great Plains Section (331F) *(REDRAWN)*

i. Upland Plains Subsection (331Fa)

a. Rolling Plains Landtype Assn. (331Fa1)

b. Parallel Cuesta and Valley Complex Landtype Assn. (331Fa3)
i. W. side of Black Hills

c. Single Cuesta Landtype Assn. (331Fa4)
i. Old Woman Creek Hills

d. Recessional Escarpment Land Type Assn. (331Fa5)
i. Hat Creek Breaks

e. Dissected Anticline Landtype Assn. (331Fa6)
i. Hartville Uplift

f. Major River Valley Landtype Assn. (331Fa7)
i. No. Platte River Valley

g. Dissected Pediment Landtype Assn. (331Fa8)
i. Laramie Peak Pediments

ii. Goshen Hole Subsection (331Fb)

b. Powder River Basin Section (331G) *REDRAWN*

i. Upland Plains Subsection (331Ga)

a. Rolling Plains Landtype Assn. (331Ga1)

b. Dune-mantled Plains Landtype Assn. (331Ga2)
i. W. border of plains

c. Parallel Cuesta and Valley Complex Landtype Assn.(331Ga3)
i. E. border of Bighorn Mountains
ii. Pine Ridge

d. Recessional Escarpment Land Type Assn. (331Ga5)
i. Duck Creek Breaks

e. Major River Valley Landtype Assn.(331Ga7)
i. No. Platte River Valley

ii. Dissected Plains Subsection (331Gb) (Powder River Breaks)

iii. Scoria Hills Subsection (331Gc)

B. Temperate Steppe Regime Mountains (M330)

1. Black Hills Coniferous Forest Province (M334)

a. Black Hills Section (M334A) *(REDRAWN)*

i. Dissected Plateau Subsection (M334Aa) (Inyan Kara Plateau)

ii. Bear Lodge Mountains Subsection (M334Ab)

iii. Interior (Red) Valley Subsection (M334Ac)

iv. **Black Hills Subsection (M334Ad)**

2. Southern Rocky Mountain Steppe-Open Woodland Coniferous Forest-Alpine Meadow Province (M331)

a. Bighorn Mountains Section (M331B)

i. **Bighorn Mountains Subsection (M331Ba)**

b. Northern Parks and Ranges Section (M331I)

i. **Laramie Mountains Subsection (M331Ic)**

C. Temperate Desert Division (340)

1. Intermountain Semi-Desert Province (342)

a. Central Basin and Hills Section (342F)

i. **Shirley Basin Subsection (342Fe)**

5.2 Rationales and Descriptions of Domain, Divisions and Provinces

The entire 7-county map area falls within the "Dry Domain" (300) as defined by Bailey et al. (1994).

The work area subtends the following three divisions according to Bailey et al. (1994):

1) the Temperate Steppe Division (330),
2) the Temperate Steppe Regime Mountains (M330) (not named as a division but treated as such by Bailey et al.), and
3) the Temperate Desert Division (340) (Fig. 10).

The map area is primarily steppe and mountain. The Temperate Desert Division is represented only by a small part of the Shirley Basin in the far southwest corner of the area, most of which is south and west of the Converse County boundary.

It happens that the map area includes only one Province in the Temperate Steppe Division--the Great Plains-Palouse-Dry Steppe Province (331). Therefore, within the domain of the map product we have produced, the Province and Division are the same.

In contrast, The Temperate Steppe Regime Mountains (division) consists of two provinces--the Black Hills Coniferous Forest Province (M334), and the Southern Rocky Mountain Steppe-Open Woodland Coniferous Forest-Alpine Meadow Province (M331) (Fig. 10).

Only a small area of Temperate Desert Division (340) is included in this map area and therefore it includes only one province, the Intermountain Semi-Desert Province (342). As a result, Fig. 10, showing Divisions and Provinces of the 7-county work area consists of only four units: one steppe province congruent with the Temperate Steppe Division, two mountain provinces, and one temperate desert province congruent with the Temperate Desert Division.

The delineations for these provinces by us are generally the same as mapped by Bailey et al. (1994) but are different in detail as we followed relatively detailed coverages of geology, and especially--relief (Fig. 10).

5.3 Sections and Subsections of the Great Plains-Palouse-Dry Steppe Province (331)

Referring back to the criteria for "Sections" in ECOMAP (1993), we see that they are:

> "broad areas of similar geomorphic process, stratigraphy, geologic origin, drainage networks, topography, and regional climate. Such areas are often inferred by relating geologic maps to potential natural vegetation "series" groupings as mapped by Kuchler (1964). Boundaries of some Sections approximate geomorphic provinces (for example, Blue Ridge) as recognized by geologists. Section names generally describe the predominant physiographic feature upon which the ecological unit delineation is based, such as Flint Hills, Great Lakes Morainal, Bluegrass Hills, Applachian Piedmont."

Two Sections mapped by Bailey et al. (1994) at 1:7,500,000 and described by McNab and Avers (1994) occur within our map area. These are:

Northwestern Great Plains Section (331F)
Powder River Basin Section (331G)

These sections broadly overlap in all their characteristics (McNab and Avers 1994) such that they seem mainly to be generalizations based primarily on conceptualizations of vegetation by Kuchler (1964)--conceptualizations that do not match the more detailed and updated vegetation data compiled by the Wyoming GAP Program (Fig. 9).

In seeking precedents for a physiographic description of this, we have found it named the "Powder River Basin" within the larger "Missouri Plateau" (Keefer 1974). While the view of this as part of the Missouri Plateau is a traditional one (Fenneman

1931), the Powder River designation for Keefer's map unit is inaccurate on grounds of both structural geology and hydrology. Keefer's map boundary for the Powder River Basin is much larger than either. In fact, this area encompasses seven river drainages: the Powder River, the Little Powder River, the Little Missouri River, the Belle Fourche River, The Cheyenne River, the Niobrara River and the North Platte River, all of which ultimately empty into the Missouri river.

Using our various spatial data sets, we have given serious consideration to whether or how sectional divisions might be imposed on the Great Plains-Palouse-Dry Steppe Province (331) falling within our map area. None of our thematic data sets including elevation (Fig. 5), geology (Fig. 3), land cover (Fig. 9), precipitation (Fig. 8) nor the available state-wide soils map (Agric. Res. Sta. 1977) correspond well with the cartographic delineations for these Sections as mapped by Bailey et al. (1993).

Perhaps the most ecologically meaningful basis for a sectional division is suggested by the decline of Wyoming big sagebrush in the steppe mosaic from northwest to southeast along a north-south line more or less parallel to the western boundaries of Crook and Weston Counties and just west of the Niobrara County line (Fig. 9). This is a fuzzy transition; there are large areas of grass dominance west of this line, and considerable Wyoming big sage and silver sage east of that line. However, that line is also generally conformable with the eastern limit of the Ft. Union Tullock member (Tft). There may be a weak tendency for sagebrush to be more important on the more coarsely textured soils of the Ft. Union Fm. than the more finely textured Cretaceous shales to the east (Lance (Kl) and Pierre (Kp)) but we do not wish to make too much of this generalization.

There is a weak and sporadic topographic tendency for ridge formation along parts of the Tullock member of the Ft. Union which also weakly supports the positioning of a sectional dividing line here. The differences are slight, however, and would probably not be recognizable at all points along the line to a land manager in the field.

Soil Great Groups do not change congruently with the Tullock-Lance boundary (Agric. Res. Sta. 1977). With increasing grass dominance to the east, one might anticipate a shift from Entisols and Aridsols to Mollisols from west to east, but in fact, Entisols and Aridisols dominate on both sides of this boundary. In fact, the shift to Mollisols occurs to the south along a line more or less congruent with Hat Creek Breaks in central Niobrara County at the boundary of Oligocene White River Fm. (Twr) and the early Miocene sediments (Tmo) (Fig. 3). This may be a good place to locate the sectional divide between the Northwestern Great Plains Section and the Central High Plains (331H) but it falls mostly outside of our present map area.

Inasmuch as we prefer to maintain a physiographic basis for all delineations at this scale, we are not enthusiastic about using very general vegetational trends as a basis for a sectional boundary. We prefer to view vegetation as an effect of a physical factor--

not a basis for such a delineation. We present this sectional boundary with some apprehension and misgivings as this rather artificial delineation does not fulfill our self-query about recognizability in the field. This boundary may be useful at the scale of state-wide or regional mapping, but it will be difficult to defend in the field.

With these caveats, we have adopted the present names for the two sections for our delineated sections given by Bailey et al. (1994) and McNab and Avers (1994) for the two sections located in this area. These names are "Powder River Basin" for the western, sagebrush-rich area to the west, and "Northwestern Great Plains" for the sagebrush-poorer area to the east.

5.3.1 Northwestern Great Plains Section

We have divided the Northwestern Great Plains Section into two Subsections, namely:

Upland Plains Subsection (12,890 km^2--4,976 mi^2)
Goshen Hole Subsection

According to Table 2, Subsections should fall within the range of 10's to low 1000's of square miles. The Upland Plains Subsection is within that range within this map area but will be well beyond that range when we consider that it extends beyond this map area. At this time we see no basis for subdividing it further, however. Areas of low relief and extensive geological features are likely to be considerably larger than the ECOMAP guideline suggests. Statistical data characterizing the subsections and Landtype Associations come from the entire 7-county area which includes the former work on the Buffalo Resource Area as well as the contiguous northeastern portion of the Great Plains--the target area for this contract. Statistics do not include mapped areas lying outside these county boundaries. An area calculation for the Goshen Hole Subsection is not given as it falls outside of the 7-county area.

5.3.1.1 Upland Plains Subsection

The Upland Plains Subsection encompasses most of the Section, serving as a sectional matrix within which the other Subsections fall (Fig. 11). It represents the little-differentiated rolling plains of the section. It will be described further in terms of its constituent Landtype Associations.

5.3.1.2 Goshen Hole Subsection

The Goshen Hole Subsection actually falls out of the four county map area but is indicated in our mapped overlap area in Goshen County. This land unit is a well-known, well-described (Fenneman 1931, Osterkamp et al. 1987) part of the High Plains. Delineation of the small part of Goshen Hole occurring in the map area was based on the lower edges of the rims as could be discerned with Thematic Mapper data.

Goshen Hole is a great widening of the North Platte River starting near Torrington, WY and extending downstream into Nebraska. It results from downcutting by the North Platte followed by widening back from the river valley itself into the soft Arikaree and White River Formations, in large part by spring sapping, seepage erosion, and related processes (Osterkamp et al. 1987). In its entirety, mostly outside of the map area, Goshen Hole is about 5,000 km^2 in area and rimmed on both the northern and southern edges by recessional escarpments. The original vegetation was grassland with riparian vegetation along the North Platte and its tributaries, but considerable tillage agriculture, including both dryland and irrigated farming are common in the Hole itself.

Because Goshen Hole is outside of our mapping area, we have not subdivided it into possible Landtype Associations.

5.3.2 Powder River Basin Section

Within the Powder River Basin Section we have delineated three Subsections. These are:

Upland Plains Subsection (27,455 km^2--10,600mi^2)
Dissected Plains Subsection (5,542 km^2--2,140 mi^2)
Scoria Hills Subsection (3,140 km^2--1,212 mi^2)

Except for the Upland Plains Subsection (see note on the analogous situation in the Northwestern Great Plains Section above) these units are comfortably within the range of 10's to low 1000's of square miles predicated by ECOMAP (1994).

5.3.2.1 Upland Plains Subsection

The Upland Plains Subsection bears the same matrical relationship to the Powder River Basin Section as the Subsection of the same name does in the Northwestern Plains Section. As in that former case, it represents the little differentiated rolling plains of the section. It will be described further in terms of its constituent Landtype Associations.

5.3.2.2 Dissected Plains Subsection

The Dissected Plains Subsection is a discreet area of intense, fine-grained dissection in the center of the gently sloping Powder River Basin (Figs. 6 and 7). The geographic name for this Subsection is the Powder River Breaks. This Subsection was delineated in the previous BRA study by digitizing around the heads of ravines as viewed on 90 m DEM data. As 30 m DEM data have become available during the period of this work, we can see that the boundary of this Subsection should be changed, mainly expanded outward.

The Dissected Plains Subsection (Powder River Breaks) is quite large within the 7-county area, comprising 2,140 mi^2 in area. Within this map area, this subsection averages 1,277 m in elevation and the coefficient of variation (CV) for elevation is only 3.82 % (Appendix, Table 3). The CV is one way to describe irregularity in terrain. In this case, the Powder River Breaks is an area having fine-grained variability in elevation over a narrow range of elevation. This high degree of dissection is made possible by erosion of the poorly consolidated Wasatch Fm. (88 %) (and a much smaller area of the Ft. Union Fm.--7.7 %) by the Powder River and its tributaries.

Precipitation in the Powder River Breaks averages 36.1 cm annually. Regionally dominant soils are shallow Torriorthents on the uplands and include Torrifluvents, Haplargids and Torriorthents in the flood plains according to Wyoming General Soil Map (Agricultural Experiment Station, University of Wyoming 1977). Vegetation is primarily sagebrush steppe (70 %) and mixed grass prairie (15 %) on the undissected interfluves and slopes running down to the incised ravines. Vegetation is relatively scant on the steep, eroding ravine walls, but relatively luxuriant deciduous riparian vegetation (5 %) and agricultural cover types (7 %) occur on the fans at the mouths of the ravines and out on the broader floodplain terraces.

This area is relatively uniform in its topographic patterns and can be considered to consist of a single Landtype Association of the same name as the Subsection.

5.3.2.3 Scoria Hills Subsection

The Scoria Hills Subsection is also a relatively discrete unit featuring a line of irregular hills formed from a capstone of scoria (clinker) resulting from coal seams burning from the last 1.4 Ma to the present (Heffern et al. 1993) in various members of the Ft. Union Fm. (70 %) and some of the Wasatch Fm. (27 %). We have delineated the Scoria Hills from a map of scoria, or clinker, prepared by Mr. Ed Heffern (Fig. 4), but as with the Powder River Breaks, we believe that it is has been too narrowly delineated in terms of relief after having seen 30 m DEM data for the area. From 30 m DEM data it can be seen that the landscape features associated with mesas, scarps, talus slopes and fans of this unit go beyond the limit of the mapped scoria itself.

This subsectional area is 1,212 mi^2. Mean elevation is 1,332 m. The CV for elevation is 6.43 %, roughly double that of the Powder River Breaks. Average annual precipitation is 37.6 cm; dominant soils are not shown on the Wyoming General Soil Map. Vegetation consists of pines (24 %) on particularly rocky sites, and Wyoming big sagebrush (40 %) and mixed grass prairie (28 %) on fans and flats surrounding the scoria-capped ridges and hills. Dryland agriculture represents only 3 % of the area.

This Subsection can also be considered to be one Landtype Association by the same name.

5.4 Landtype Associations of the Great Plains Province

Because we think the Sectional division within this Province is artificial, at least within this map area, and because the Landtype Associations we have identified sometimes occur within both of the Sections (Table 3), we present the Landtype Associations here for both Sections at once. Within these two Sections, we have delineated Landtype Associations for only the "Upland Plains Subsections." At this time it seems to us that the other subsections in our map area (Powder River Breaks and Scoria Hills) are sufficiently unique and homogeneous to serve essentially as very large Landtype Associations--a perspective warranting future review.

Areas recommended for Landtype Associations by ECOMAP (1994) are 100's to 1,000's of acres. Statistics for area and other variables given for the following Landtype Associations apply to the 7-county area (c.f. Appendix).

5.4.1 Rolling Plains Landtype Association

Just as the "Upland Plains Subsection" is the matrical type for each of the two Sections of this Province, the Rolling Plains Landtype Association is the matrical Landtype Association for the two Upland Plains Subsections within the map area (Fig. 11). This Landtype Association encompasses 33,040 km^2, or 12,757 mi^2 representing 67 % of the Province occuring within the 7-county area. These Landtype Associations are larger than prescribed in the guidelines for this hierarchical unit as given in ECOMAP (1994) but we do not see a physiographic basis for subdividing them any further. In fact, these Landtype Associations in the two Subsections were mapped by successive exclusion of the other Landtype Associations imbedded within the Subsections--they are the indivisible residuals.

Within the Northwestern Great Plains Section, this Landtype Association occurs on the Cretaceous Lance Fm. (31 %), Pierre Shale (21 %), Fox Hills Sandstone (5 %): and on the Tertiary White River Fm. (9 %), and late Oligocene-early Miocene Formation referred to by Love and Christiansen (1985) as Tmo (22 %). Within the Powder River Basin Section, the Rolling Plains Landtype Association occurs primarily on the Wasatch Fm. (55 %) and various members of the Ft. Union Fm. (36 %).

With the exception of some resistant members of the Ft. Union Fm and areas of the Fox Hills Sandstone, these are mainly weakly to poorly indurated beds that are easily eroded. Since late Tertiary time, they have developed a gentle topographic form. The landscape mainly features broad interfluves separated by more active slopes closer to the tributaries of the several rivers draining the area (Blackstone 1971). In restricted areas, the terrain can become relative rough, almost badlands in nature, particularly along the south and southwestern edges of the Cheyenne River drainage. We did not think these areas could be defined sharply enough that we could isolate them as different Landtype Associations.

Average elevation for the "Rolling Plains Landtype Association" in the Northwestern Great Plains Section is 1,329 m and its coefficient of variation for elevation is 10.07 %. Average elevation for the same Landtype Association" in the Powder River Basin Section is 1,434 m (coefficient of variation 12.38 %). Coefficient of variation is not a good measure of terrain irregularity for this Landtype Association because the Association extends over such a large area that it encompasses a considerable range in average elevation (Fig. 5) not part of local relief.

Average annual precipitation in the Northwestern Section is 35.6 cm and in the Powder River Section is 35.5 cm. Soils are mainly Haplargids, Paleargids and Torriorthents (Agric. Exp. Sta. 1977). Vegetation in the Northwestern Great Plains section consists of mixed grass prairie (74 %), Wyoming big sagebrush steppe (7 %) and dryland agriculture (4 %) on the uplands, and greasewood and some saltbush along some terraces, particularly in the eastern extent, especially on the more saline Pierre Shale Formation (Fig. 9). Vegetation in the Powder River Basin Section consists of 40 % mixed grass prairie, 40 % Wyoming big sagebrush and 5 % dryland farmland. See the sections on "Grasslands" and "Sagebrush Steppe" in Knight (1994) for further ecological description of landscapes in this Landtype Association.

5.4.2 Dune-mantled Plains Landtype Association

A relatively small area in this Province is covered with Pleistocene and Holocene sand deposits that have been blown into the area from the West. We refer to this as the Dune-mantled Plains Landtype Association (Fig. 11). This unit was delineated from both the geology coverage for Quaternary sand, and Thematic Mapper data that showed a slightly greater extent of sand-covered terrain. This unit is only 347 km^2 (134 mi^2) in area but is much more extensive where it continues westward into Natrona County. It has an average elevation of 1,654 m (CV= 4.76 %). The general landform is fundamentally the same as for areas not mantled with the sand, but there is a superposition of sand of varying depths that ranges from stable, indurated, and, in fact, fluvially eroding deposits, to unvegetated, unstable and mobile sand beds. As delineated, the surface geology of this Landtype Association is 82 % Quaternary Sand and 10 % Wasatch Fm.

Average annual precipitation is 34.8 cm. The sand gives the soils a special character and they fall into the Torripsamments Great Group. Vegetation is strongly affected by the sand mantle and is generally more mesic than on more finely-textured soils. In this climate, sand permits deep percolation of precipitation and snow melt so that for species with deep roots, water is more available through the growing season than is generally the case on the more loamy to clayey soils of the rest of the Subsection. Some plant species more commonly found on these sandy areas are blowout grass

(Redfieldia flexuosa), Indian ricegrass (Oryzopsis hymenoides), needle-and-thread grass (Stipa comata), prairie sandreed (Calomovilfa longifolia), scurfpea (Psoralea tenuifolia), antelope bitterbrush (Purshia tridentata), rabbitbrush (Chrysothamnus nauseousus), and silver sagebrush (Artemisia cana) (Knight 1994). According to the land cover data coverage (Fig. 9) vegetation consisted of mixed grass prairie (74 %), Wyoming big sagebrush (18 %) and vegetated dunes (8 %). Clearly, the land cover map was not able to discriminate between mixed grass prairie and vegetated dunes in this case.

Because of the sandy soil, different plant cover, and vulnerability to destabilization, this Landtype Association deserves special attention from a management viewpoint.

5.4.3 Parallel Cuesta and Valley Landtype Association

Laramide tectonics dominate the structural geology of most of Wyoming. Faulting and uplift during the Cretaceous and early Tertiary brought Precambrian basement rock to the surface in many places throughout the state. Congruent with this activity, the overlying Paleozoic and Mesozoic sedimentary rocks surrounding the Precambrian uplifts of the state were uplifted, tilted and deformed. Over millions of years of uplift and erosion, these deformed rocks have been mantled by thousands of feet of Tertiary sediments (Lillegraven and Ostresh 1988) and subsequently exhumed by at least two erosional cycles. The second exhumation is only partially complete.

Where Tertiary deposits do not cover the tilted Paleozoic and Mesozoic rocks paralleling the fault block mountains, sedimentary rocks occur as more or less parallel ridges (referred to as cuestas) and intermittent valleys of uniformly tilted sedimentary rocks. This geologic situation is extremely common and widespread in Wyoming, both adjacent to mountains, and as independent anticlines and synclines unassociated with the mountains. These more or less parallel cuesta-valley complexes are treated as a distinctive terrain type we refer to as the generic "Parallel Cuesta-Valley Landtype Association." The adjective "parallel" is used here because there are other cases in which only one cuesta intercepts the basal plain constituting another Landtype Association. This Landtype Association is included in the "Escarpment and Foothill Transition" by Knight in his ecological treatment of Wyoming landscapes (Knight 1994).

The Parallel Cuesta-Valley Landtype Association is manifested along the west side of Black Hills and as a long and complex sequence paralleling the Bighorn Mountains and extending into broad anticlines along the western margin of the map area (Fig. 11). The example along the western edge of the Black Hills (area = 1,943 km^2) is relatively subdued and intermittent compared with the other occurrence. The average elevation for the Black Hills example is 1,225 m (CV = 9.76 %). Even though its topographic pattern is subdued, the underlying geology still controls the direction of minor streams and sets a pattern of parallel zones of different soils and vegetation. This example is bounded on the west by the western edge of the Niobrara Formation and

Carlisle Shale (Knc) (8 %), includes the Greenhorn Formation, and Belle Fourche and Mowrey Shales (Kgbm) (45 %), the Newcastle Sandstone and Skull Creek Shale (Kns) (24 %), and generally stops at the base of the (Inyan Kara Group (KJ) (6 %). In fact, in some areas the boundaries were modified from geologically defined lines to delineations base on relief derived from 30 m DEM data, particularly along the northern extent.

Average annual precipitation for the Black Hills example of Parallel Cuesta-valley Landtype Association is 38.6 cm. Soils are not easily generalized because of the alternating nature of the parent material but are mapped as shallow Torriorthents (Ag. Exper. Sta. 1977). Ponderosa pines occur on some of the more resistant cuestas (17 % of the area); the intermittent valleys are basically mixed grass prairie (52 %) and Wyoming big sagebrush (7 %).

The second example of a Parallel Cuesta-Valley Landtype Association is the extensive unit ranging from the northern end of the Big Horn Mountains in Sheridan County down to Pine Ridge located in northwestern Converse County and adjacent Natrona and Johnson Counties. This system is composed of intermittently resistant and erodible layers of the Chugwater and Goose Egg Fm. (10 %), Cody Shale (9 %), Frontier Fm. (9 %), Mowry and Thermopolis Shales (7 %), Lance Fm. (7 %), Mesa Verde Fm. (6 %), Ft. Union Fm. (24 %), and a number of other geological units. The area bounded by the 7-county map area is 3,005 km^2 in extent; average elevation is 1,581 m (CV = 8.43 %); average annual precipitation is 40.7 cm (the wettest Landtype Association in the Province in this map area); and soils are primarily shallow Torriorthents. Ponderosa pine forms woodlands and closed forests on rocky ridges (9 %) and considerable area is in xeric shrubs such as curlleaf mahogany (5 %). Matrical vegetation is primarily Wyoming big sagebrush steppe (43 %) and mixed grass prairie (29 %).

5.4.4 Single Cuesta Landtype Association

As noted in the foregoing, there are occasions in which cuestas produced by single formations rise above the basal plain as ridges having distinctive character from the surrounding landscape. We refer to this as a Single Cuesta Landtype Association. We have only one representative of this Landtype Association in the map area, the Old Woman Creek Hills located in east-central Niobrara County (Fig. 11). This is a low ridge of resistant Cretaceous rocks (mostly Cloverly Fm. (KJ) (23 %), Newcastle Sandstone and Skull Creek Shale (Kns) (12 %) and Greenhorn Formation, and Belle Fourche and Mowrey Shales (Kgbm) (45 %) rising from the surrounding plain of Pierre Shale (Kp). Average elevation is 1,281 m with a CV of 3.29 %. This is a small unit (64.5 km^2) and it might be argued that this should be designated a "landtype," a unit lower in the ECOMAP hierarchical series, rather than a Landtype Association. Average precipitation is 34.8 cm, soils are the same as for the Black Hills representative of the Multiple Cuesta-Valley Landtype Association. Since this is mostly a ridge of resistant rock, it features pine woodland (34 %) in a matrix of mixed grass prairie (55 %).

5.4.5 Recessional Escarpment Land Type Association

A very conspicuous feature of eastern Wyoming and the Great Plains further east into South Dakota and Nebraska are long rims, buttes and mesas resulting from headward erosion through soft, more or less horizontally bedded, sedimentary formations, usually Tertiary in age, by the dominant drainages of the region (Osterkamp et al. 1987). Sometimes the bases of these rims include spurs of soft, rapidly eroding, non-vegetated sediments referred to as "badlands." We refer to this complex of broken terrain as the Recessional Escarpment Land Type Association. Knight (1994) includes these kinds of escarpments in his ecological treatment of "Foothill and Escarpment Transition." Two examples of this Landtype Association within the map area are Hat Creek Breaks extending along an east-west line across Niobrara County into eastern Converse County, and Duck Creek Breaks in northern Campbell and Crook Counties (Fig. 11).

Hat Creek Breaks is a prominent escarpment formed by the southward erosion of the flat-lying Tmo Fm. (98 %) by tributaries of the Cheyenne River to the north. Further east in Nebraska, this escarpment is prominently known as the Pine Ridge escarpment where it marks the boundary between the High Plains Section of the Great Plains Physiographic Province from the Missouri Plateau to the north (Fenneman 1931, Osterkamp et al. 1987). This geographic relationship between these physiographic provinces is paralleled by the change in soils from Entisols and Aridisols to the north with Mollisols to the south. Together, these conditions support the merit of designating this position as the boundary line between the Northwestern Great Plains to the north and the Central High Plains to the south as described earlier.

Hat Creek Breaks is a relatively small area of 185 km^2. It consists of a nearly level slope on the south rim, deeply incised and actively eroding slopes to the north, almost badlands in places, and long fans extending northward to the Cheyenne drainage (Blackstone 1971). Average elevation is 1,514 (CV = 4.07 %). Soils are mapped as shallow Torriorthents (Agric. Res. Sta. 1977). Precipitation averages 39.8 cm/yr (Fig. 8). In this broken terrain, ponderosa pine and Rocky Mountain juniper (71 %) are very prominent within a matrix of mixed grass prairie (21 %).

Duck Creek Breaks is located in northern Campbell and Crook Counties as an interfluve of the parallel Little Powder River and Little Missouri River. Structurally, this interfluve is a gentle cuesta of mostly the Tullock member of the Ft. Union Fm. (72 %). The dip slope of the cuesta to the west is highly dissected by tributaries of the Little Powder River (only one of which is Duck Creek), and the east, or strike slope, is dissected by the tributaries of the Little Missouri River. Technically, only the east slope can be correctly characterized as a recessional escarpment.

Duck Creek Breaks is 968 km^2 in extent. Elevation averages 1,229 m (CV = 6.44 %). Precipitation averages 37.3 cm/yr. Soils are generally mapped as shallow Torriorthents. There is considerable ponderosa pine (20 %) scattered throughout a mosaic of mixed grass prairie (36 %) and sagebrush steppe (34 %). Eight percent of the area is in dryland agriculture.

5.4.6 Dissected Anticline Landtype Association

Extending southwestward from Niobrara County into northern Platte County lies a broad, asymmetric anticline, fault-bounded on its southeastern margin--the Hartville Uplift (Fig. 11). This uplift partially breaches the Tertiary mantle (Tmo) (66 %) as a dissected rise of Paleozoic sedimentary rocks, etched by valleys formed during an earlier erosional cycle that are still filled with Tertiary mantle. The Paleozoic rocks are limestones, sandstones and dolomites of the Hartville Limestone (PPh) (24 %), and small amounts of Guernsey Fm. (MDg) (5 %). Along the eastern, fault-bounded extent of the Uplift, occur small ridges and tors of Precambrian granites (3.4 %). This geologic feature is unique in this map area and we have established a possibly unique land form class we term "Dissected Anticline Landtype Association." While a better generic term may be devised, the area is well know by its local geographic epithet--the Hartville Uplift.

The southeastern boundary of the Hartville Uplift was digitally delineated by our linking outliers of limestone and granite associated with the southeastern fault line. The southern and western delineations followed limestone outcrops. The northwestern boundary was set by linking the limestone spurs that descend into the Tertiary mantle along that limb of the anticline.

Topographically, the Hartville Uplift consists of gently dipping limestone and sandstone surfaces incised by dendritic drainages extending mostly northwestward and southwestward. The Paleozoic uplands have thin soils and steep slopes which, in places, bear Rocky Mountain juniper and ponderosa pine (27 %). The valleys have relatively deep soils (Argiustolls) and carry excellent mixed grass prairie (55 %). Nine percent of the area is classified as Wyoming big sagebrush steppe. The area represented by the Hartville Uplift is small in Niobrara County, 260 km^2; it lies mainly in Platte County to the south. Within Niobrara County it has an average elevation of 1,666 m (CV = 4.9 %). Average annual precipitation is 37.8 cm.

5.4.7 Major River Valley Landtype Association

Transecting the southern end of this section is the valley of the North Platte. This, the largest river in the map area, has carved a major valley into the plains and canyons through the more resistant rocks of the region. We have identified this as a representative of a "Major River Valley Landtype Association"--an association occurring in adjacent and other parts of the state. Geomorphologically, this high-order river has entrenched a significant valley through a number of different formations and deposited Quaternary alluvium through most of its length. In the Northwestern Great Plains Section, 52 % of it lies on White River Fm. (Twr) material and 42 % on Quaternary Alluvium (Qa). In the Powder River Section, 53 % is covered with Quaternary Alluvium, 19 % on the Lebo member of the Ft. Union Fm, and the rest on other Tertiary and Cretaceous rocks.

Although we have only been able to map it from the bases of the valley walls, ideally, it would be correct to include its valley walls along with its older, dissected terraces and younger little-dissected terraces with in-stream fluvial features. We experienced considerable difficulty in making the valley wall base delineations, even where 30 m DEM data were available, and recognize that our highest level of delineation error is associated with the difficult judgements we had to make in this case. Where the river cuts through resistant rocks and narrows down to canyons we have not recognized it as an independent Landtype Association, but rather as a Land Type within the encompassing Landtype Association.

The total area of this Landtype Association in the two Sections in which it occurs is 265 km^2. Average elevation for its occurrence in the Northwestern Great Plains Section is 1,445 m (CV = 1.24 %); in the upstream Powder River Basin Section is 1,510 m (CV = 1.94 %). Except for the valley walls, it features gentle topography (elevational CV's less than 2 %) in close proximity to irrigation water. Consequently, it is highly developed from an agricultural point of view. In the Northwestern Great Plains Section, most of the vegetation is a mixture of irrigated (65 %) and non-irrigated agriculture (6 %) interwoven with a broad range of natural upland and riparian vegetation types and disturbed lands. In the Powder River Basin Section, this Landtype Association consists of 30 % forest riparian vegetation, 26 % mixed grass prairie, 20 % Wyoming big sagebrush and 15 % irrigated agriculture. See Knight's chapter on "Riparian Landscapes" (Knight 1994) for further ecological description of this Landtype Association. Soils are generally Torrifluvents.

5.4.8 Dissected Pediment Landtype Association

Along the interface of many Precambrian mountain blocks with adjacent basins, more or less horizontally bedded Tertiary material, as well as tilted Paleozoic and Mesozoic rocks, have been cut by lateral planation into very long, cantilevered slopes, extending well into surrounding basins. These long sloping plains composed of varying rock types often extend from high positions on mountains out into surrounding basins. When the planation processes that formed these plains cut across bedding planes, these land forms are termed "pediments" (Blackstone 1971). Most of the pediments extending from Wyoming mountains have resulted from removal of Tertiary fill and thus are very old, and, themselves well dissected. For this type of situation we have coined the term "Dissected Pediment Landtype Association." Dissected pediments extend around the northeastern corner of the Laramie Range as it turns northwestward from its main northerly trend. The principal feature in this area is the highest peak of this range--Laramie Peak--and we have given these pediments the local geographic designation of "Laramie Peak Pediments."

The Laramie Peak Pediments in the map area consist primarily of the White River Formation (Twr) (51 %), plus late Miocene, unnamed materials designated as Tmu (29 %) (Love and Christiansen 1985). Further south in Platte County, Tmu is the dominant parent material of this Association. These pediments are deeply creased by long, parallel streams running in a radiate pattern easterly and northeasterly from the bend in the range. We have delineated the pediments from the Laramie Range proper by the boundary line between Precambrian rocks of the mountains and Tmu or White River materials belonging to the pediments. Delineating the lower boundary to the east was more problematic. Somewhere, the long cantilever slope of pediments blends into the horizontally bedded Tertiary materials of the plains. Somewhat arbitrarily we have placed that eastern boundary at the border between Tmu and Tmo materials where they occur, at the edge of the Hartville Uplift in the center of this unit, and to the edge of the North Platte River northwest of the Hartville Uplift.

Most of the Laramie Peak Pediments occur in Platte County and only a small portion falls within Converse County. The following characteristics are based solely on the portion falling within Converse County, an area of only 268 km^2. The average elevation is 1,589 m and the moderately high CV for elevation (6.92 %) is indicative of the considerable elevational change from the upper end to the lower ends of these slopes, not necessarily to their local roughness. Precipitation averages 33.5 cm/yr. The soils of this area are mapped as Torriorthents. The dissection of these pediments is so advanced in some areas, and the materials sufficiently durable, to support ponderosa pine (2 %) and mountain mahogany (10 %) where the terrain is particular broken and rocky. Otherwise, long slopes of this Landtype Association mainly support a mosaic of sagebrush steppe (41 %), mixed grass prairie (16 %) and some irrigation agriculture (15 %). Where pediments are quite highly dissected, Knight (1994) treats them as foothills; where they are relatively planar, they are treated as plains. The Laramie Peak Pediments contain ecological components of both.

5.5 Sections and Subsections of the Black Hills Coniferous Forest Province (M334)

As shown in Fig. 10, we have considerably expanded the Black Hills Coniferous Forest Province in Wyoming beyond that mapped by Bailey et al. (1994). Inasmuch as we do not know how those authors established that Province boundary, we cannot explain why their delineation is placed where it is. The basis for our delineations will follow below.

The Black Hills Section (M334A) is equivalent to the Black Hills Coniferous Forest Province and we have adopted the same nomenclature. Our major effort within this section has been to delimit four Subsections within Wyoming. These are rather large land units deserving of subsectional status, but they are so physiographically homogeneous that they, like some subsections of the Dry Steppe Province, can be treated as Landtype Associations as well. It is conceivable that they could be ranked as Landtype Associations within Subsections of the same name.

Our interpretation of Black Hills physiography in Wyoming differs from that of Fenneman (1931) and others. Starting on the western border, the Black Hills are rimmed by cuestas and intervening valleys that might be viewed as part of the Black Hills themselves. But, along the western boundary of the Black Hills, these cuestas are rather weakly and sporadically displayed and the intervening valleys are rather broad, so it seemed to us that they, and other Parallel Cuesta and Valley Landtype Associations should be associated with the plains.

5.4.1 Dissected Plateau Subsection

East of the Parallel Cuesta-Valley belt, a very massive limestone-sandstone, Cretaceous formation, named the Inyan Kara Group (KJ) in the Black Hills rises from the Powder River Basin to the west with a high angle dip which soon changes to a very low angle dip, particularly in the northwestern extent of the Black Hills physiographic province (Fig. 3). The dip is so low, and the Formation so thick, that for much of its exposure in Wyoming it forms a plateau rather than a cuesta. This plateau is highly dissected, however, with numerous smaller streams along with the prominent Belle Fourche River whose course was set across this relatively resistant rock antecedent to the exhumation of the landscape from the Tertiary mantle. We have termed this the Inyan Kara Plateau and placed it in a generic unit termed the Dissected Plateau Subsection (Fig. 11).

The Inyan Kara Plateau was delineated primarily by exposure of the Inyan Kara Group (48 %), but we followed relief surrounding this plateau in the detailed delineation which sometimes occurred eastward of the Inyan Kara boundary, but more often extended westward and northward of it, particularly in the northwest where we included considerable land on Newcastle Sandstone and Skull Creek Shale (Kns) (11 %). On the eastern margin, we included Sundance and Gypsum Springs Formations (25 %) where they lapped up on the Inyan Kara Group. The total extent of the plateau in Wyoming is 3,993 km^2.

The plateau surface varies significantly from 1,000 m in the northeastern corner, to 1,200 m in the northwestern corner, to 1,900 m in the southern end in Wyoming. For the entire Wyoming extent, including dissected valleys, the average elevation for this land unit is 1,340 m (cv = 11.33 %). Precipitation averages 47.6 cm over the Inyan Kara Plateau; soils are mapped as Torriorthents on the plateau according to the Agricultural Experiment Station Report (1977), and as Torrifluvents in the major valleys such as the valley of the Belle Fourche River. Most of the plateau is covered with ponderosa pine forest and woodland (52 %) interrupted by mixed grass prairie (27 %), and in the valleys, agricultural lands (16 %). Knight (1994) describes the landscape ecology of the Plateau and other Subsections of the Black Hills Section in his special chapter on "The Black Hills, Bear Lodge Mountains, and Devil's Tower."

5.4.2 Bear Lodge Mountains Subsection

The western Black Hills are famous for Devil's Tower and other intrusive rock outcrops including Missouri Buttes and Inyan Kara Mountain, itself. These are scattered about as erosional remnants too small to map. However, a relatively large intrusive unit is recognized here as the Bear Lodge Mountains Subsection. This small mountainous area is composed of Tertiary Intrusives (Tie) (25 %) with a limited area of upper Miocene rocks (Tmu) (17 %) which have eroded in an entirely different manner than the nearly flat-lying sedimentary rocks of the Inyan Kara Plateau nearly surrounding them. Rather than having deep-set canyons with very steep to near vertical walls, the Bear Lodge Mountains are gently rounded and have a regular system of radiating drainages apparently unrelated to possible heterogeneities in the rock structure.

This Subsection was delineated generally by geological contacts between the Intrusives plus some basal units of Paleozoic limestone and sandstone (Pzr--12 %, PPm--12 %, Pmo--11 %) together with fragments of Miocene mantle with surrounding Mesozoic rocks of the Inyan Kara Plateau and Interior Valley. In fact, as is usually the case in our delineations, the final boundaries were set at the base of the mountains as determined with 30 m DEM data. This is a relatively small, if unique, Subsection--only 137 km^2 in area.

The highest point in these mountains--Warren Peak--is 2,027 m, and the average elevation is 1,720 m (CV = 7.26 %). Average precipitation is 62.5 cm, considerably higher than the Plateau surrounding this small range. These mountains are mainly covered with ponderosa pine forest (84 %) but they have areas of substantial bur oak, aspen and small amounts of paper birch (5 %). The highest points are mainly in grassland (10 %). Soils of the forests and woodlands are Eutroboralfs, and of the grasslands are Haploborolls (Agric. Exper. Sta. 1977).

5.4.3 Interior (Red) Valley Subsection

Running almost completely around the inner Black Hills is a distinct valley dominated by a highly erodible, red-colored Spearfish Fm (TrPs). This is locally known as the "red valley" due to the strong red color of the soil, or as the "race track" because of its circumferential nature around the inner part of the Black Hills. We have designated it as the "Interior (Red) Valley Subsection" of this Black Hills Section. The Red Valley is generally delimited by geology, including the Spearfish Fm. (55 %), parts of the adjacent Sundance and Gypsum Springs Formations (Jsg) (2 %), and parts of the very dense, slabby Minnekahta Limestone (Pmo) (30 %) rising from the valley to the interior part of the Black Hills. But as in other cases, the final control on the delineations was local relief as revealed by 30 m DEM data. The valley is delimited by more or less steeply rising, continuous valley walls to the west and the east.

The Red Valley is 699 km^2 in area and has a mean elevation of 1,512 m. Although the valley is very distinct from the adjacent mountainous or plateau sections, it has considerable elevational change within it. In fact, the elevational CV is 14.46 %, the second highest CV of all the land units delineated in this work. This is explained by the fact that the valley rises from the northern end, which is at an elevation of about 1100 m, to about 1950 m near the southern end. Past this high point, the valley rapidly drops to about 1400 m at the southernmost end. Erosion is a notable feature on the Spearfish Fm. whereas extremely resistant limestone slabs characterize the Minnekahta limestone. Precipitation averages 55.6 cm; soils are mapped as Torriorthents, Argiustolls and Haplustolls (Agric. Exper. Sta. 1977). Vegetation is primarily grassland, some of it improved pasture (42 %), dryland and irrigated agriculture (37 %) with some second-growth pine woodland (20 %).

5.4.4 Black Hills Subsection

Rising to the east of the Red Valley are the interior Black Hills which we have designated the "Black Hills Subsection." We have bounded this Subsection by the intersection of the resistant Minnekahta Limestone (Pmo) (22 %) with the Minnelusa Formation (PPm)--a soft limestone (66 %). At the center of this Subsection is a small complex of plutonic and intrusive rocks (3.8 %).

This Subsection is 684 km^2 in extent, has an average elevation of 1,616 m, slightly less than the Bear Lodge Mountains Subsection. The CV for elevation is 13.05 %, less than for the Red Valley but more than for the Bear Lodge Mountains. Precipitation averages 63.7 cm/yr, the highest of all land units in this study. Soils are mapped as Eutroboralfs (Agric. Exper. Sta. 1977). The topography consists of even, relatively gentle slopes composing the radiative drainages, all rising to the high center on the South Dakota border. The Subsection is mostly vegetated by ponderosa pine (71 %) but many of the valley bottoms are grass-dominated (5 %) and fringed with aspen and bur oak (13 %). As delineated, this section contains approximately 8 % of the area in forms of agriculture.

5.5 Sections and Subsections of the Southern Rocky Mountain Steppe-Open Woodland Coniferous Forest-Alpine Meadow Province (M331)

We have adopted the Sectional and Subsectional nomenclature of Bailey et al. (1994) and McNab and Avers (1994) for these parts of the Rocky Mountains, and have not attempted to subdivide them into Landtype Associations as they were of marginal interest for this contract directed toward delineations of the Great Plains Physiographic Province. Accordingly, we have adopted the Bighorn Mountains Section (M331B), and have assumed that it must entirely represent the Bighorn Mountains Subsection.

Similarly, we have adopted the designation of Northern Parks and Ranges Section (M331I) for the Laramie Mountains and likewise assumed they would be represented by the Laramie Mountains Subsection.

The delineations of these sections differ from the Bailey et al. (1994) map in detail, however, mostly through our use of more detailed GIS data, and perhaps through inclusion of Parallel Cuesta and Valley Landtype Associations, and Dissected Pediment Landtype Associations as part of the plains rather than the mountains (Fig. 10).

5.6 Sections and Subsections of the Intermountain Semi-Desert Province (342)

This Province occurs in only a tiny portion of far southwestern Converse County and is not part of the Great Plains Physiographic Province. Nevertheless, we have recognized this Province, as well as the Central Basin and Hills Section (342F) in the larger view of our map products, and assume that the portion shown will be designated the Shirley Basin Subsection. We have done no map work here except for delineation of the western boundary of the Laramie Mountains based on geology and relief in combination.

6.0 CONTRACT PRODUCTS

A list of contract products was written in the original contract but has been revised in discussion with Mr. William Daniels (9 Feb. 1995) to include the following:

Copies of contract report (8); distributed as follows:
- Wyoming State Office (3)
- Casper District Office (3)
- Buffalo Resource Area (2)

Paper prints of coverages and map product (4 sets)

Slide copies of coverages and map product (4 sets)

Digital data for coverages and map product (1 set) to be in
- Arc/Info format, and to include,
- All GIS data coverages for the 4-county area,
- Map unit coverage for the 7-county area.

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8.0 FIGURES

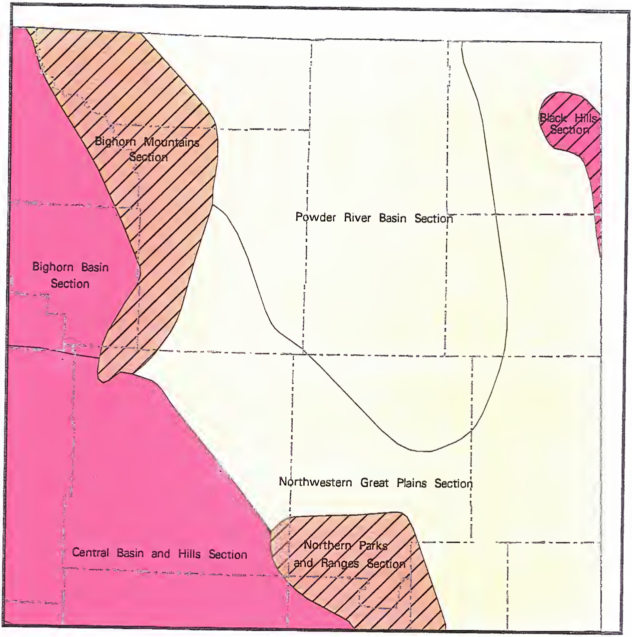


Fig. 1. Delineations of Sections according to Bailey et al. (1994) for the 7-county area of northeastern Wyoming.

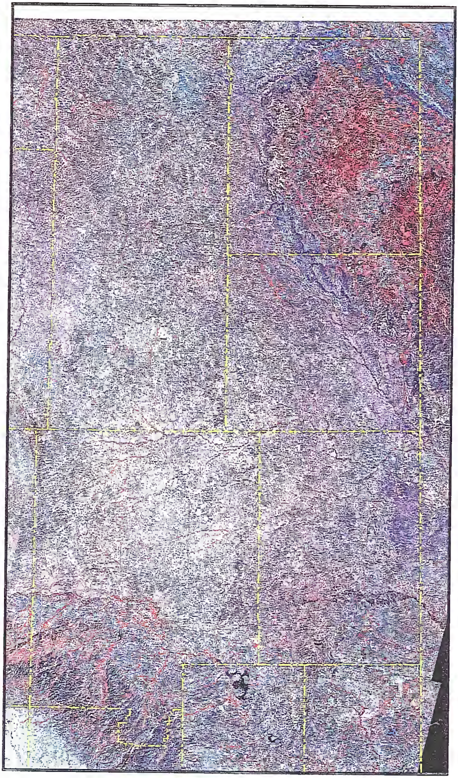


Fig. 2 Mosaic of Thematic Mapper data resampled to 100 m using bands 4, 5 and 3 rendered in red, green and blue, respectively, for the 5-county area of northeastern Wyoming.

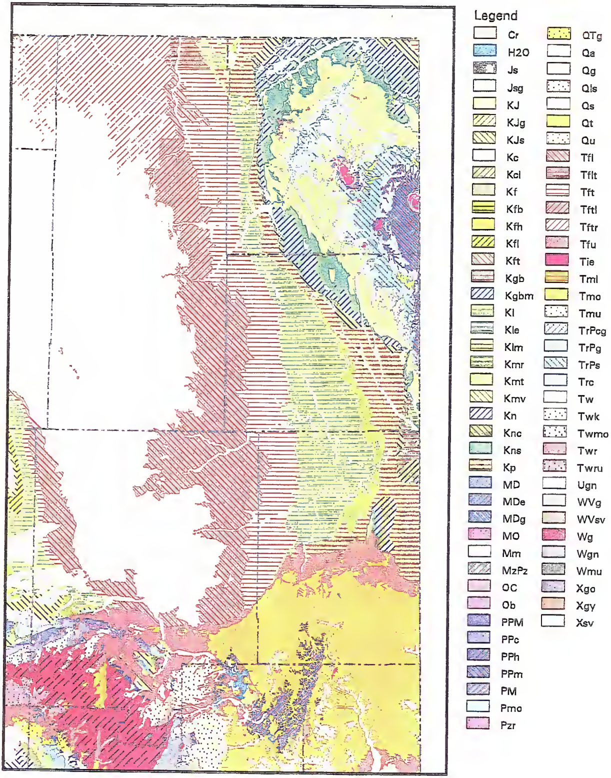


Fig. 3. Geology of the 5-county area of northeastern Wyoming derived from Love and Christiansen (1985).

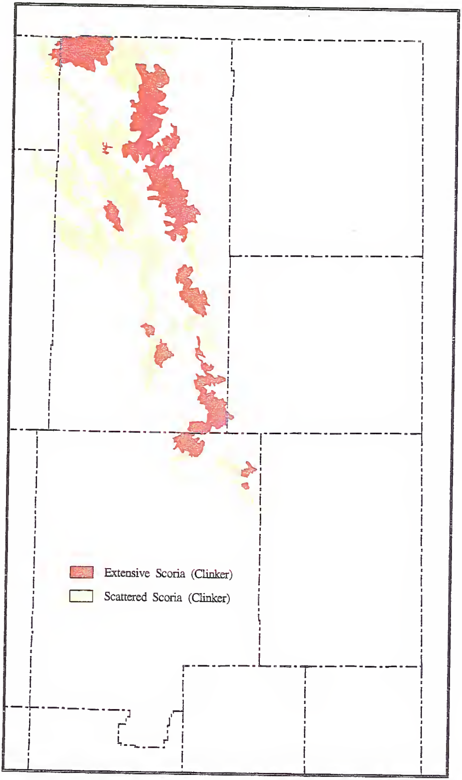


Fig. 4. Areas of extensive scoria (clinker) and scattered scoria as mapped by Mr. Ed Heffern of the Wyoming State Office of BLM.

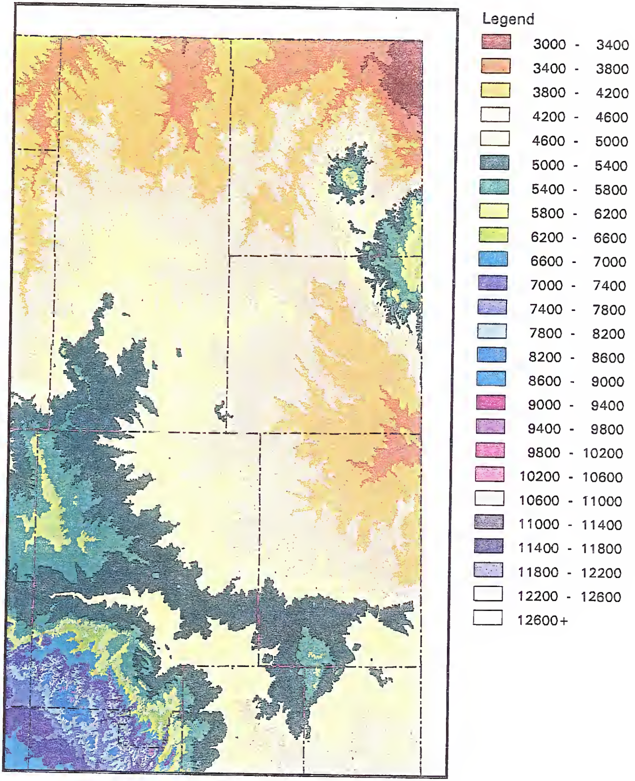


Fig. 5. Elevations for the 5-county area of northeastern Wyoming as they occur in 400 ft. intervals as derived from "90 m" DEM data.

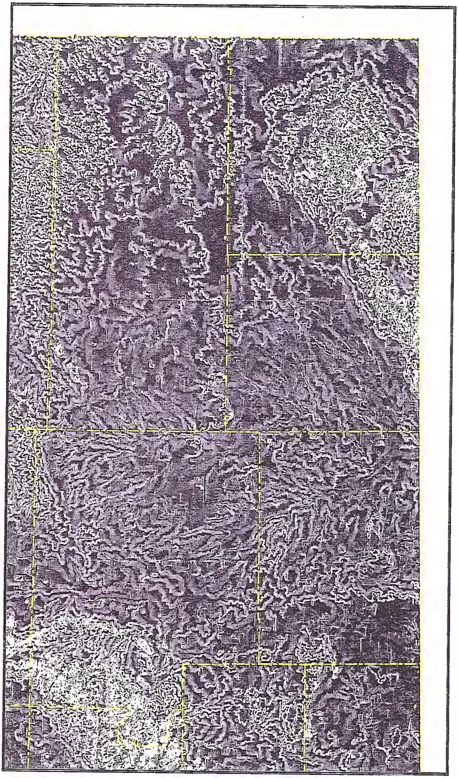


Fig. 6. "Slope" derived from 90 m data for the 5-county map area. Brighter lines indicate steeper slopes.

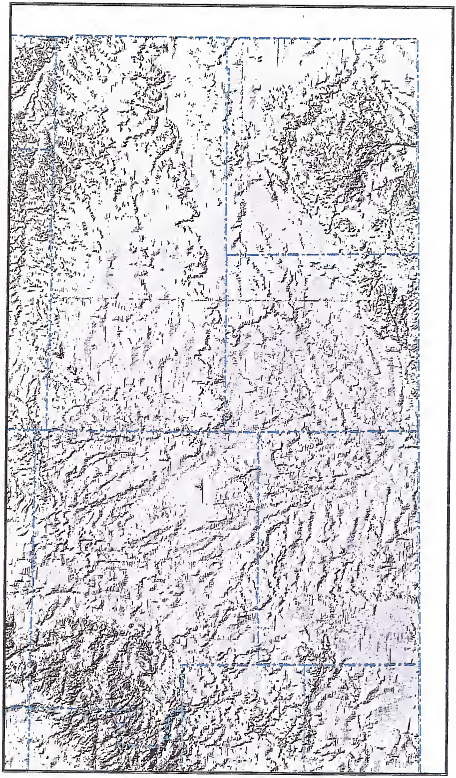


Fig. 7. "Shaded relief" image derived from 90 m data for the 5-county area. Shadows are created by placement of the sun in the northwestern sky.

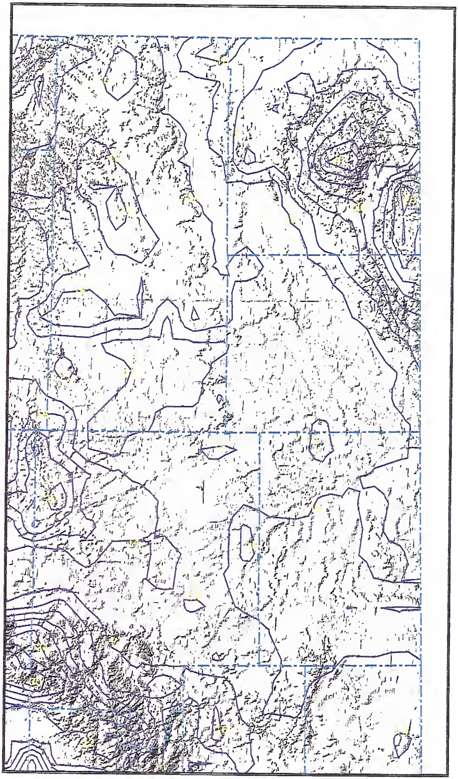


Fig. 8. Mean annual precipitation isolines shown over shaded relief for the 5-county area. See text for the source of these precipitation estimates.

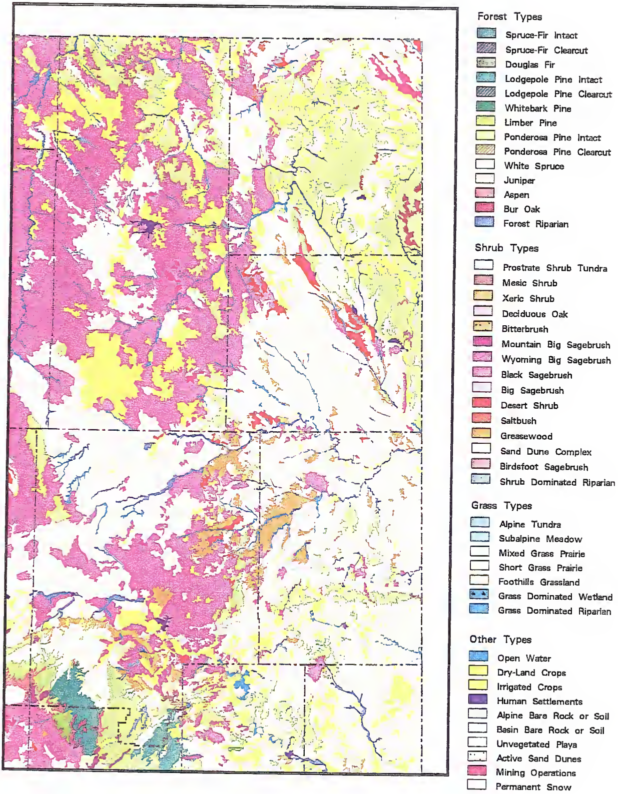
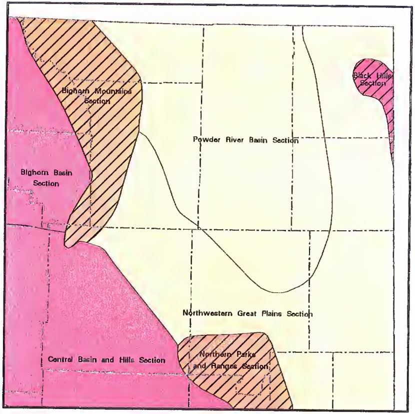
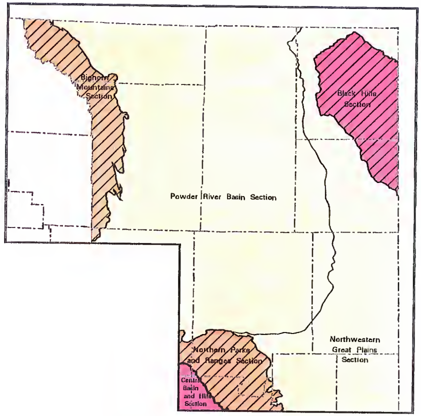


Fig. 9. Land cover for the 5-county area derived from the Wyoming GAP land cover map.

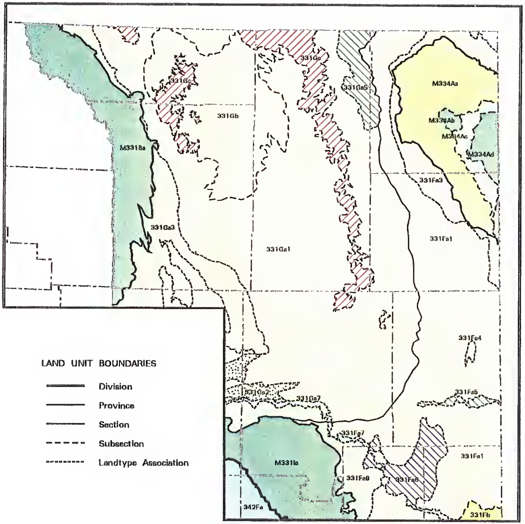


ECOMAP Ecological Units (Sections)



UW Land Units (Sections)

Fig. 10. Comparisons of Sectional delineations by Bailey et al. (1994) and Reiners and Thurston (this study) for the 7-county area of northeastern Wyoming.



LAND UNIT CODES

Northwestern Great Plains Section (331F)

331Fa Upland Plains Subsection

Landtype Associations
- 331Fa1 Rolling Plains
- 331Fa3 Parallel Cuesta and Valley Complex
- 331Fa4 Single Cuesta
- 331Fa5 Recessional Escarpment
- 331Fa6 Dissected Anticline
- 331Fa7 Major River Valley
- 331Fa8 Dissected Padiment

331Fb Goshen Hole Subsection

Powder River Basin Section (331G)

331Ga Upland Plains Subsection

Landtype Associations
- 331Ga1 Rolling Plains
- 331Ga2 Dune-mantled Plains
- 331Ga3 Parallel Cuesta and Valley Complex
- 331Ga5 Recessional Escarpment
- 331Ga7 Major River Valley

331Gb Dissected Plains Subsection

331Gc Scoria Hills Subsection

Bighorn Mountains Section (M331B)

M331Ba Bighorn Mountains Subsection

Northern Parks and Ranges Section (M331I)

M331Ic Laramie Mountains Subsection

Black Hills Section (M334A)

M334Aa Dissected Plateau Subsection

M334Ab Bear Lodge Mountains Subsection

M334Ac Interior (Red) Valley Subsection

M334Ad Black Hills Subsection

Central Basin and Hills Section (342F)

342Fa Shirley Basin Subsection

Fig. 11. Land unit delineations for the 7-county area of northeastern Wyoming as defined by Reiners and Thurston in this study.

9.0 APPENDIX

STATISTICAL TABLES FOR LAND UNITS AND DESCRIPTIONS

FOR LAND COVER AND GEOLOGY CODES

Table 1. Areas[1] of delineated land units of the 7-county area (Sheridan, Johnson, Campbell, Crook, Weston, Niobrara, and Converse). Full names of the land units symbolized by the codes in column one are given in Table 3 of the main text.

Land Unit Code	Meter^2	Hectares	Kilometer^2	Acres	Mile^2
331Fa1	10,092,016,312	1,009,202	10,092.02	2,493,737	3,896.53
331Fa3	1,943,479,168	194,348	1,943.48	480,234	750.38
331Fa4	64,498,452	6,450	64.50	15,938	24.90
331Fa5	184,682,528	18,468	184.68	45,635	71.31
331Fa6	259,847,964	25,985	259.85	64,208	100.33
331Fa7	77,805,808	7,781	77.81	19,226	30.04
331Fa8	267,890,224	26,789	267.89	66,196	103.43
331Ga1	22,947,754,324	2,294,775	22,947.75	5,670,390	8,860.13
331Ga2	346,719,160	34,672	346.72	85,674	133.87
331Ga3	3,005,385,742	300,539	3,005.39	742,631	1,160.38
331Ga5	968,192,704	96,819	968.19	239,240	373.82
331Ga7	186,835,424	18,684	186.84	46,167	72.14
331Gb	5,541,810,688	554,181	5,541.81	1,369,381	2,139.69
331Gc	3,140,128,878	314,013	3,140.13	775,926	1,212.40
342Fe	15,527,713	1,553	15.53	3,837	6.00
M331Ba	4,424,260,608	442,426	4,424.26	1,093,235	1,708.21
M331Ic	2,274,203,648	227,420	2,274.20	561,956	878.07
M334Aa	3,993,380,352	399,338	3,993.38	986,764	1,541.84
M334Ab	136,747,088	13,675	136.75	33,790	52.80
M334Ac	698,965,056	69,897	698.97	172,714	269.87
M334Ad	683,918,784	68,392	683.92	168,996	264.06
Total	61,254,049,792	6,125,405	61,254.05	15,135,876	23,650.19

[1]Conversion factors: 1 $m^2 = 10^{-4}$ hectares $= 10^{-6}$ km^2
$= 2.471X10^{-4}$ acres $= 3.861X10^{-7}$ mile^2

Table 2. Elevation data for delineated land units of the 7-county area (Sheridan, Johnson, Campbell, Crook, Weston, Niobrara, and Converse). See the methods section for information on how the statistics were calculated using 90 m DEM data. Full names of the land units symbolized by the codes in column one are given in Table 3 of the main text.

Land Unit Code	Sample Points	Area [hectares]	Elevation [meters] Mean	Min	Max	STD	Coef. of Variation [%]
331Fa1	1,043,989	1,009,202	1,328.83	973	1,707	133.80	10.07
331Fa3	201,013	194,348	1,224.70	975	1,645	119.52	9.76
331Fa4	6,672	6,450	1,280.94	1,207	1,402	42.16	3.29
331Fa5	19,093	18,468	1,514.34	1,381	1,705	61.60	4.07
331Fa6	26,883	25,985	1,665.59	1,412	1,847	81.60	4.90
331Fa7	8,049	7,781	1,444.60	1,412	1,514	17.91	1.24
331Fa8	27,682	26,789	1,588.85	1,422	1,922	109.97	6.92
331Ga1	2,373,920	2,294,775	1,434.47	1,029	2,033	177.56	12.38
331Ga2	35,891	34,672	1,654.49	1,516	1,884	78.83	4.76
331Ga3	310,875	300,539	1,580.99	1,203	2,201	133.24	8.43
331Ga5	100,182	96,819	1,228.63	1,035	1,402	79.13	6.44
331Ga7	19,357	18,684	1,509.82	1,462	1,660	29.37	1.94
331Gb	573,301	554,181	1,277.44	1,063	1,463	48.84	3.82
331Gc	324,896	314,013	1,331.73	1,036	1,595	85.57	6.43
342Fe	1,589	1,553	2,327.35	2,254	2,366	30.94	1.33
M331Ba	457,685	442,426	2,452.19	1,280	3,928	373.85	15.25
M331Ic	235,256	227,420	2,051.04	1,481	2,822	291.90	14.23
M334Aa	413,155	399,338	1,339.91	975	1,920	151.87	11.33
M334Ab	14,148	13,675	1,719.95	1,402	2,022	124.93	7.26
M334Ac	72,271	69,897	1,511.66	1,089	1,951	218.58	14.46
M334Ad	70,724	68,392	1,615.79	1,097	2,012	210.89	13.05
Total		6,125,405					

Table 3. Annual precipitation data for delineated land units of the 7-county area (Sheridan, Johnson, Campbell, Crook, Weston, Niobrara, and Converse). See the methods section for information on how the statistics were calculated. Full names of the land units symbolized by the codes in column one are given in Table 3 of the main text.

Land Unit Code	Sample Points	Area [hectares]	Annual Precipitation [millimeters] Mean	Min	Max	STD	Coef. of Variation [%]
331Fa1	1,044,028	1,009,202	356.24	297	472	23.18	6.51
331Fa3	201,039	194,348	385.71	316	494	43.14	11.18
331Fa4	6,672	6,450	347.77	344	349	0.00	0.00
331Fa5	19,093	18,468	397.52	355	409	15.59	3.92
331Fa6	26,883	25,985	377.78	300	405	22.79	6.03
331Fa7	8,049	7,781	320.46	300	333	13.88	4.33
331Fa8	27,682	26,789	334.95	300	455	25.66	7.66
331Ga1	2,373,920	2,294,775	355.48	278	685	44.33	12.47
331Ga2	35,891	34,672	347.68	310	519	64.33	18.50
331Ga3	310,875	300,539	406.67	299	690	90.86	22.34
331Ga5	100,182	96,819	373.23	322	472	37.93	10.16
331Ga7	19,357	18,684	344.46	308	432	40.57	11.78
331Gb	573,301	554,181	361.03	284	685	59.67	16.53
331Gc	324,896	314,013	376.69	285	545	53.74	14.27
342Fe	1,589	1,553	551.15	551	784	6.35	1.15
M331Ba	457,685	442,426	609.21	309	1299	168.37	27.64
M331Ic	235,256	227,420	476.89	325	784	122.06	25.60
M334Aa	413,165	399,338	475.71	323	718	70.78	14.88
M334Ab	14,148	13,675	624.70	491	718	84.82	13.58
M334Ac	72,271	69,897	555.79	383	735	68.35	12.30
M334Ad	70,759	68,392	637.18	383	735	98.87	15.52
Total		6,125,405					

Table 4. Land cover data for delineated land units of the 7-county area (Sheridan, Johnson, Campbell, Crook, Weston, Niobrara, and Converse). See the methods section for information on how the data were calculated. Full names of the land unit codes are given in Table 3 of the main text. The land cover codes are defined in Table 5 of the appendix.

Land Unit Code	Land Cover Code	Area [hectares]	Area as Percent of Total [%]
331Fa1	31001	749,345	74.25
331Fa1	32007	69,793	6.92
331Fa1	21001	35,832	3.55
331Fa1	74001	31,600	3.13
331Fa1	32012	28,824	2.86
331Fa1	42010	21,316	2.11
331Fa1	21002	17,652	1.75
331Fa1	61001	14,515	1.44
331Fa1	62003	12,976	1.29
331Fa1	32010	12,947	1.28
331Fa1	62001	8,751	0.87
331Fa1	32011	2,235	0.22
331Fa1	42015	1,890	0.19
331Fa1	11001	485	0.05
331Fa1	75001	402	0.04
331Fa1	32001	331	0.03
331Fa1	32002	307	0.03
331Fa3	31001	101,508	52.23
331Fa3	42010	32,225	16.58
331Fa3	75001	15,415	7.93
331Fa3	32007	13,787	7.09
331Fa3	32010	12,044	6.20
331Fa3	21002	11,234	5.78
331Fa3	21001	1,910	0.98
331Fa3	11001	1,700	0.87
331Fa3	32012	1,697	0.87
331Fa3	62001	1,297	0.67
331Fa3	52001	691	0.36
331Fa3	61001	424	0.22
331Fa3	62003	389	0.20
331Fa3	32011	27	0.01
331Fa4	31001	3,549	55.03
331Fa4	42010	2,183	33.84
331Fa4	74001	405	6.28
331Fa4	61001	310	4.80
331Fa4	32012	3	0.05
331Fa5	42010	13,168	71.30
331Fa5	31001	3,964	21.46
331Fa5	74001	507	2.75
331Fa5	32007	309	1.67
331Fa5	32001	308	1.67
331Fa5	21001	193	1.05
331Fa5	21002	19	0.10
331Fa6	31001	14,219	54.72
331Fa6	42010	7,022	27.03
331Fa6	32007	2,464	9.48
331Fa6	21001	852	3.28

Table 4 continued

Land Unit Code	Land Cover Code	Area [hectares]	Area as Percent of Total [%]
331Fa6	21002	791	3.05
331Fa6	74001	498	1.92
331Fa6	42015	82	0.32
331Fa6	61001	53	0.20
331Fa6	52001	3	0.01
331Fa7	21002	5,100	65.54
331Fa7	32007	609	7.83
331Fa7	32010	456	5.86
331Fa7	21001	438	5.63
331Fa7	11001	356	4.57
331Fa7	74001	273	3.51
331Fa7	52001	261	3.36
331Fa7	31001	146	1.88
331Fa7	75001	98	1.25
331Fa7	32002	37	0.47
331Fa7	62001	5	0.06
331Fa7	42015	3	0.04
331Fa8	32007	10,885	40.63
331Fa8	31001	4,363	16.29
331Fa8	21002	4,032	15.05
331Fa8	32002	2,715	10.13
331Fa8	74001	1,508	5.63
331Fa8	32006	989	3.69
331Fa8	75001	934	3.49
331Fa8	32010	518	1.93
331Fa8	42010	427	1.59
331Fa8	62001	175	0.65
331Fa8	32008	129	0.48
331Fa8	42015	91	0.34
331Fa8	61001	23	0.08
331Ga1	31001	920,858	40.13
331Ga1	32007	916,359	39.93
331Ga1	21001	118,700	5.17
331Ga1	21002	82,396	3.59
331Ga1	42010	55,868	2.43
331Ga1	32012	53,360	2.33
331Ga1	61001	42,662	1.86
331Ga1	62003	41,022	1.79
331Ga1	32010	23,198	1.01
331Ga1	75001	10,302	0.45
331Ga1	11001	9,521	0.41
331Ga1	62001	7,592	0.33
331Ga1	74001	5,114	0.22
331Ga1	32013	1,641	0.07
331Ga1	32001	1,586	0.07
331Ga1	42015	1,491	0.06
331Ga1	32002	1,287	0.06
331Ga1	52001	919	0.04
331Ga1	41001	898	0.04
331Ga2	31001	25,717	74.17
331Ga2	32007	6,096	17.58
331Ga2	32013	2,856	8.24
331Ga2	61001	4	0.01
331Ga3	32007	129,634	43.13

Table 4 continued

Land Unit Code	Land Cover Code	Area [hectares]	Area as Percent of Total [%]
331Ga3	31001	88,463	29.43
331Ga3	42010	25,908	8.62
331Ga3	32002	15,031	5.00
331Ga3	21002	13,063	4.35
331Ga3	42015	7,540	2.51
331Ga3	61001	6,287	2.09
331Ga3	74001	5,125	1.71
331Ga3	32001	4,074	1.36
331Ga3	21001	3,418	1.14
331Ga3	62003	747	0.25
331Ga3	32013	540	0.18
331Ga3	42004	316	0.11
331Ga3	41001	199	0.07
331Ga3	32012	129	0.04
331Ga3	42003	35	0.01
331Ga3	74002	18	0.01
331Ga3	52001	11	0.00
331Ga5	31001	34,598	35.73
331Ga5	32007	32,956	34.04
331Ga5	42010	19,789	20.44
331Ga5	21001	7,707	7.96
331Ga5	62003	874	0.90
331Ga5	21002	543	0.56
331Ga5	61001	354	0.37
331Ga7	61001	5,536	29.63
331Ga7	31001	4,909	26.27
331Ga7	32007	3,781	20.24
331Ga7	21002	2,888	15.46
331Ga7	11001	1,392	7.45
331Ga7	32012	178	0.95
331Gb	32007	389,177	70.23
331Gb	31001	83,294	15.03
331Gb	61001	26,489	4.78
331Gb	21001	22,950	4.14
331Gb	21002	15,791	2.85
331Gb	42010	10,838	1.96
331Gb	62001	3,110	0.56
331Gb	32012	1,822	0.33
331Gb	62003	586	0.11
331Gb	52001	124	0.02
331Gc	32007	126,812	40.38
331Gc	31001	86,808	27.64
331Gc	42010	74,797	23.82
331Gc	21001	10,396	3.31
331Gc	62003	4,359	1.39
331Gc	61001	3,738	1.19
331Gc	75001	2,173	0.69
331Gc	21002	1,969	0.63
331Gc	52001	1,340	0.43
331Gc	32012	778	0.25
331Gc	62001	684	0.22
331Gc	74001	159	0.05
342Fe	32006	968	62.35
342Fe	32007	399	25.68

Table 4 continued

Land Unit Code	Land Cover Code	Area [hectares]	Area as Percent of Total [%]
342Fe	41001	186	11.97
M331Ba	42004	154,686	34.96
M331Ba	31001	98,781	22.33
M331Ba	82002	61,709	13.95
M331Ba	42010	43,245	9.77
M331Ba	42007	23,218	5.25
M331Ba	42003	19,420	4.39
M331Ba	42001	16,054	3.63
M331Ba	82001	8,977	2.03
M331Ba	74002	3,947	0.89
M331Ba	41001	2,822	0.64
M331Ba	42016	2,703	0.61
M331Ba	32002	2,493	0.56
M331Ba	62001	1,521	0.34
M331Ba	32001	1,132	0.26
M331Ba	52001	400	0.09
M331Ba	32006	317	0.07
M331Ba	61001	299	0.07
M331Ba	21002	280	0.06
M331Ba	91001	262	0.06
M331Ba	74001	138	0.03
M331Ba	62003	15	0.00
M331Ba	32007	8	0.00
M331Ic	31001	76,578	33.67
M331Ic	42010	60,531	26.62
M331Ic	42004	20,177	8.87
M331Ic	32007	20,110	8.84
M331Ic	32002	19,257	8.47
M331Ic	21002	10,319	4.54
M331Ic	42015	7,948	3.50
M331Ic	32006	5,117	2.25
M331Ic	41001	3,203	1.41
M331Ic	62001	1,591	0.70
M331Ic	21001	1,079	0.47
M331Ic	74001	551	0.24
M331Ic	61001	457	0.20
M331Ic	52001	262	0.12
M331Ic	42009	240	0.11
M334Aa	42010	208,129	52.12
M334Aa	31001	106,872	26.76
M334Aa	21002	44,484	11.14
M334Aa	21001	20,488	5.13
M334Aa	61001	11,141	2.79
M334Aa	32007	5,250	1.31
M334Aa	41002	831	0.21
M334Aa	62001	738	0.18
M334Aa	52001	720	0.18
M334Aa	41001	528	0.13
M334Aa	32010	101	0.03
M334Aa	11001	47	0.01
M334Aa	62003	8	0.00
M334Aa	75001	1	0.00
M334Ab	42010	11,455	83.77
M334Ab	31001	1,392	10.18
M334Ab	41002	686	5.01

Table 4 continued

Land Unit Code	Land Cover Code	Area [hectares]	Area as Percent of Total [%]
M334Ab	21002	142	1.04
M334Ac	31001	29,245	41.84
M334Ac	21002	14,095	20.17
M334Ac	42010	13,902	19.89
M334Ac	21001	11,703	16.74
M334Ac	11001	566	0.81
M334Ac	61001	358	0.51
M334Ac	32007	24	0.03
M334Ac	41002	4	0.01
M334Ad	42010	48,783	71.33
M334Ad	41002	8,575	12.54
M334Ad	21002	3,534	5.17
M334Ad	31001	3,433	5.02
M334Ad	21001	2,091	3.06
M334Ad	61001	1,977	2.89

Table 5. Wyoming land cover types.

Forest Types

41001 - Aspen
41002 - Bur oak
42001 - Spruce-fir intact
42002 - Spruce-fir clearcut
42003 - Douglas fir
42004 - Lodgepole pine intact
42007 - Lodgepole pine clearcut
42008 - Whitebark pine
42009 - Limber pine
42010 - Ponderosa pine intact
42013 - Ponderosa pine clearcut
42014 - White spruce
42015 - Juniper woodland
42016 - Burned Conifer
61001 - Forest riparian

Shrub Types

32001 - Mesic shrub
32002 - Xeric shrub
32003 - Deciduous oak shrub
32005 - Bitterbrush
32006 - Mountain big sagebrush
32007 - Wyoming big sagebrush
32008 - Black sagebrush
32009 - Big sagebrush
32010 - Desert shrub
32011 - Saltbush
32012 - Greasewood
32013 - Vegetated dunes
32014 - Birdsfoot sagebrush
62001 - Shrub dominated riparian
81001 - Prostrate shrub tundra

Grass Types

31001 - Mixed grass prairie
31002 - Short grass prairie
31003 - Foothills grassland
62002 - Grass dominated wetland
62003 - Grass dominated riparian
82001 - Alpine tundra
82002 - Subalpine meadow

Other Types

11001 - Human settlement
21001 - Non-irrigated agriculture
21002 - Irrigated agriculture
52001 - Open water
71001 - Unvegetated playa
73001 - Active dunes
74001 - Basin bare rock or soil
74002 - Alpine bare rock or soil
75001 - Mining operations
91001 - Permanent snow or glacier

Table 6. Geology data for delineated land units of the 7-county area (Sheridan, Johnson, Campbell, Crook, Weston, Niobrara, and Converse). See the methods section for information on how the data were calculated. Full names of the land unit codes are given in Table 3 of the main text. The geology codes are defined in Table 7 of the appendix.

Land Unit Code	Geology Code	Area [hectares]	Area as Percent of Total [%]
331Fa1	Kl	311,927	30.92
331Fa1	Tmo	222,720	22.08
331Fa1	Kp	208,238	20.64
331Fa1	Twr	90,937	9.01
331Fa1	Kfh	53,071	5.26
331Fa1	Qa	50,456	5.00
331Fa1	Knc	19,030	1.89
331Fa1	Kcl	14,557	1.44
331Fa1	Kgbm	13,611	1.35
331Fa1	Kgb	10,116	1.00
331Fa1	Kn	7,803	0.77
331Fa1	KJ	3,155	0.31
331Fa1	Kmr	645	0.06
331Fa1	Tmu	600	0.06
331Fa1	KJs	429	0.04
331Fa1	Qt	414	0.04
331Fa1	Tw	244	0.02
331Fa1	Tft	227	0.02
331Fa1	Js	155	0.02
331Fa1	MDg	83	0.01
331Fa1	Kns	69	0.01
331Fa1	Wg	68	0.01
331Fa1	TrPg	50	0.01
331Fa1	PPh	48	0.00
331Fa1	WVsv	38	0.00
331Fa1	Trc	21	0.00
331Fa1	Xgy	18	0.00
331Fa1	Tfl	6	0.00
331Fa3	Kgbm	87,679	45.22
331Fa3	Kns	45,970	23.71
331Fa3	Qa	24,646	12.71
331Fa3	Knc	16,217	8.36
331Fa3	KJ	11,593	5.98
331Fa3	Kmr	3,237	1.67
331Fa3	Qt	1,297	0.67
331Fa3	Kgb	1,205	0.62
331Fa3	TrPs	670	0.35
331Fa3	Jsg	521	0.27
331Fa3	Qls	349	0.18
331Fa3	Kcl	212	0.11
331Fa3	Pmo	200	0.10
331Fa3	Kp	92	0.05
331Fa3	H20	16	0.01
331Fa4	Kgbm	4,137	64.14
331Fa4	KJ	1,509	23.40
331Fa4	Kns	782	12.13
331Fa4	Jsg	21	0.33
331Fa5	Tmo	18,030	97.65

Table 6 continued

Land Unit Code	Geology Code	Area [hectares]	Area as Percent of Total [%]
331Fa5	Twr	267	1.44
331Fa5	MDg	83	0.45
331Fa5	WVsv	38	0.20
331Fa5	PPh	27	0.15
331Fa5	KJ	20	0.11
331Fa6	Tmo	17,164	66.05
331Fa6	PPh	6,149	23.66
331Fa6	MDg	1,331	5.12
331Fa6	WVsv	577	2.22
331Fa6	Wg	241	0.93
331Fa6	Twr	200	0.77
331Fa6	Qs	165	0.64
331Fa6	Tmu	81	0.31
331Fa6	Xgo	71	0.27
331Fa6	TrPg	4	0.01
331Fa6	H20	2	0.01
331Fa7	Twr	4,008	51.51
331Fa7	Qa	3,233	41.55
331Fa7	H20	255	3.27
331Fa7	Trc	166	2.14
331Fa7	KJs	88	1.13
331Fa7	Tmu	13	0.16
331Fa7	Tmo	10	0.13
331Fa7	Kf	5	0.07
331Fa7	Tfl	2	0.03
331Fa8	Twr	13,567	50.64
331Fa8	Tmu	7,732	28.86
331Fa8	Trc	1,294	4.83
331Fa8	KJs	1,180	4.41
331Fa8	Qa	791	2.95
331Fa8	TrPg	628	2.34
331Fa8	Tmo	590	2.20
331Fa8	WVsv	525	1.96
331Fa8	Kf	204	0.76
331Fa8	KJ	100	0.37
331Fa8	Kmt	80	0.30
331Fa8	PPM	44	0.16
331Fa8	PPc	28	0.10
331Fa8	Kn	26	0.10
331Ga1	Tw	1,272,080	55.44
331Ga1	Tfl	368,052	16.04
331Ga1	Tft	291,104	12.69
331Ga1	Tftr	86,691	3.78
331Ga1	Qa	73,028	3.18
331Ga1	Tftl	47,237	2.06
331Ga1	Kc	39,698	1.73
331Ga1	Tfu	30,615	1.33
331Ga1	Kl	25,765	1.12
331Ga1	Twr	18,711	0.82
331Ga1	Twk	10,446	0.46
331Ga1	Kmv	8,409	0.37
331Ga1	Qt	6,660	0.29
331Ga1	Kfh	5,766	0.25
331Ga1	Tflt	4,280	0.19

Table 6 continued

Land Unit Code	Geology Code	Area [hectares]	Area as Percent of Total [%]
331Ga1	Klm	2,783	0.12
331Ga1	Qu	757	0.03
331Ga1	Qls	554	0.02
331Ga1	Twmo	539	0.02
331Ga1	Kf	408	0.02
331Ga1	KJ	224	0.01
331Ga1	Trc	147	0.01
331Ga1	Qs	116	0.01
331Ga1	TrPg	115	0.01
331Ga1	Kle	92	0.00
331Ga1	Kfb	74	0.00
331Ga1	Kft	60	0.00
331Ga1	Js	35	0.00
331Ga1	Tmu	30	0.00
331Ga1	Kmt	26	0.00
331Ga1	PPc	10	0.00
331Ga1	TrPcg	9	0.00
331Ga1	PM	4	0.00
331Ga1	MD	4	0.00
331Ga2	Qs	28,566	82.39
331Ga2	Tw	3,533	10.19
331Ga2	Kl	1,736	5.01
331Ga2	Tfl	679	1.96
331Ga2	Qa	158	0.46
331Ga3	Tfl	40,460	13.46
331Ga3	TrPcg	30,725	10.22
331Ga3	Kc	28,083	9.35
331Ga3	Kf	26,514	8.82
331Ga3	Kmt	20,991	6.99
331Ga3	Tfu	20,262	6.74
331Ga3	Kl	19,777	6.58
331Ga3	Kmv	18,282	6.08
331Ga3	Qa	17,188	5.72
331Ga3	Klm	16,502	5.49
331Ga3	Tft	11,025	3.67
331Ga3	Jsg	8,016	2.67
331Ga3	KJ	8,001	2.66
331Ga3	Qt	7,623	2.54
331Ga3	Kft	4,452	1.48
331Ga3	KJg	3,938	1.31
331Ga3	Qu	3,815	1.27
331Ga3	PM	3,145	1.05
331Ga3	TrPg	2,894	0.96
331Ga3	Kfl	2,538	0.84
331Ga3	Kfb	2,369	0.79
331Ga3	Tw	1,860	0.62
331Ga3	Trc	1,011	0.34
331Ga3	KJs	609	0.20
331Ga3	QTg	165	0.05
331Ga3	Twk	100	0.03
331Ga3	Qls	95	0.03
331Ga3	Ugn	48	0.02
331Ga3	OC	18	0.01
331Ga3	Twmo	4	0.00
331Ga5	Tft	69,597	71.97
331Ga5	Tflt	12,332	12.75

Table 6 continued

Land Unit Code	Geology Code	Area [hectares]	Area as Percent of Total [%]
331Ga5	Kl	10,914	11.29
331Ga5	Tfl	3,420	3.54
331Ga5	Qa	354	0.37
331Ga5	Kfh	90	0.09
331Ga7	Qa	9,863	52.79
331Ga7	Tfl	3,631	19.43
331Ga7	Kl	1,467	7.85
331Ga7	Kc	981	5.25
331Ga7	Tw	873	4.67
331Ga7	Qs	869	4.65
331Ga7	Tft	467	2.50
331Ga7	Twr	297	1.59
331Ga7	Kfh	115	0.62
331Ga7	Kmv	59	0.32
331Ga7	Kle	55	0.30
331Ga7	Tmo	6	0.03
331Gb	Tw	489,939	88.41
331Gb	Tftr	42,310	7.63
331Gb	Qa	21,927	3.96
331Gb	Qt	5	0.00
331Gc	Tftr	115,005	36.66
331Gc	Tw	83,500	26.62
331Gc	Tfl	66,104	21.07
331Gc	Tftl	37,173	11.85
331Gc	Qa	10,935	3.49
331Gc	H20	788	0.25
331Gc	Qt	161	0.05
342Fe	Twru	1,231	79.28
342Fe	Twr	248	15.97
342Fe	Mm	62	3.99
342Fe	PPc	7	0.46
342Fe	Wg	4	0.29
M331Ba	Ugn	97,270	21.99
M331Ba	WVg	92,783	20.97
M331Ba	PM	59,666	13.49
M331Ba	MD	47,049	10.63
M331Ba	OC	36,441	8.24
M331Ba	Mm	26,078	5.89
M331Ba	Cr	22,392	5.06
M331Ba	Qg	18,916	4.28
M331Ba	Qls	13,619	3.08
M331Ba	Ob	12,373	2.80
M331Ba	Twmo	4,069	0.92
M331Ba	Twr	3,503	0.79
M331Ba	Qu	2,696	0.61
M331Ba	Tml	1,763	0.40
M331Ba	TrPcg	1,746	0.39
M331Ba	WVsv	497	0.11
M331Ba	Qa	451	0.10
M331Ba	Wmu	342	0.08
M331Ba	TrPg	314	0.07
M331Ba	MO	178	0.04
M331Ba	QTg	135	0.03
M331Ba	Tw	71	0.02

Table 6 continued

Land Unit Code	Geology Code	Area [hectares]	Area as Percent of Total [%]
M331Ba	Qt	32	0.01
M331Ba	Twk	25	0.01
M331Ba	Kmt	7	0.00
M331Ba	Kf	4	0.00
M331Ba	KJg	4	0.00
M331Ba	KJ	2	0.00
M331Ba	Kc	1	0.00
M331Ic	Wg	104,762	46.07
M331Ic	Twr	42,855	18.84
M331Ic	Tmu	25,534	11.23
M331Ic	Wgn	12,362	5.44
M331Ic	PPc	11,078	4.87
M331Ic	Tmo	6,447	2.84
M331Ic	KJs	4,781	2.10
M331Ic	Pzr	4,156	1.83
M331Ic	Twru	2,732	1.20
M331Ic	WVsv	2,720	1.20
M331Ic	PPM	2,705	1.19
M331Ic	Trc	1,910	0.84
M331Ic	TrPg	1,350	0.59
M331Ic	Kmt	1,285	0.56
M331Ic	Kf	905	0.40
M331Ic	Qa	737	0.32
M331Ic	Tml	510	0.22
M331Ic	Kn	334	0.15
M331Ic	H20	191	0.08
M331Ic	Mm	22	0.01
M331Ic	MzPz	22	0.01
M331Ic	Qt	16	0.01
M331Ic	Kc	5	0.00
M334Aa	KJ	191,309	47.91
M334Aa	Jsg	100,139	25.08
M334Aa	Kns	45,885	11.49
M334Aa	TrPs	19,764	4.95
M334Aa	Qa	16,603	4.16
M334Aa	Qls	13,002	3.26
M334Aa	Kgbm	4,297	1.08
M334Aa	Qt	2,227	0.56
M334Aa	Twr	1,796	0.45
M334Aa	Tmo	1,628	0.41
M334Aa	Pmo	922	0.23
M334Aa	Tmu	760	0.19
M334Aa	H20	401	0.10
M334Aa	Tie	307	0.08
M334Aa	Pzr	142	0.04
M334Aa	PPm	136	0.03
M334Aa	MDe	21	0.01
M334Ab	Tie	3,398	24.85
M334Ab	Tmu	2,281	16.68
M334Ab	Pzr	1,647	12.04
M334Ab	PPm	1,605	11.74
M334Ab	Pmo	1,538	11.25
M334Ab	TrPs	1,308	9.57
M334Ab	MDe	492	3.60
M334Ab	Jsg	434	3.17
M334Ab	Qls	425	3.11

Table 6 continued

Land Unit Code	Geology Code	Area [hectares]	Area as Percent of Total [%]
M334Ab	KJ	231	1.69
M334Ab	Wg	215	1.58
M334Ab	OC	95	0.69
M334Ab	Twr	6	0.04
M334Ac	TrPs	38,331	54.84
M334Ac	Pmo	20,730	29.66
M334Ac	PPm	3,599	5.15
M334Ac	Qt	3,102	4.44
M334Ac	Qa	2,145	3.07
M334Ac	Jsg	1,553	2.22
M334Ac	MDe	210	0.30
M334Ac	Tie	179	0.26
M334Ac	KJ	48	0.07
M334Ad	PPm	45,224	66.12
M334Ad	Pmo	15,015	21.95
M334Ad	MDe	2,611	3.82
M334Ad	Tie	2,603	3.81
M334Ad	TrPs	1,174	1.72
M334Ad	OC	1,122	1.64
M334Ad	Xsv	387	0.57
M334Ad	Qt	211	0.31
M334Ad	Twr	44	0.06

Table 7. Geologic map units for the 7-county area (Sheridan, Johnson, Campbell, Crook, Weston, Niobrara, and Converse).

QUATERNARY ROCKS AND UNCONSOLIDATED DEPOSITS

Qa	ALLUVIUM AND COLLUVIUM
Qt	GRAVEL, PEDIMENT, AND FAN DEPOSITS--May include some glacial deposits and Tertiary gravels
Qg	GLACIAL DEPOSITS
Qls	LANDSLIDE DEPOSITS
Qs	DUNE SAND AND LOESS
Qu	UNDIVIDED SURFICIAL DEPOSITS

LOWER QUATERNARY AND TERTIARY ROCKS AND UNCONSOLIDATED SURFICIAL DEPOSITS

QTg	TERRACE GRAVEL (PLEISTOCENE AND/OR PLIOCENE)

UPPER AND UPPERMOST LOWER TERTIARY SEDIMENTARY AND IGNEOUS ROCKS

Tmu	UPPER MIOCENE ROCKS
Tml	LOWER MIOCENE ROCKS
Tmo	LOWER MIOCENE AND UPPER OLIGOCENE ROCKS OR ROCKS EQUIVALENT TO UPPER AND LOWER MIOCENE ROCKS AND WHITE RIVER FORMATION

LOWER TERTIARY AND UPPERMOST CRETACEOUS SEDIMENTARY AND IGNEOUS ROCKS

Twr	WHITE RIVER FORMATION
Twru	Upper conglomerate member
Tie	INTRUSIVE AND EXTRUSIVE IGNEOUS ROCKS--Incorporates masses of Mississippian through Cambrian formations
Tw	WASATCH FORMATION
Twmo	Moncrief Member
Twk	Kingsbury Conglomerate Member
Tfu	FORT UNION FORMATION
Tftr	Tongue River Member
Tftl	Tongue River and Lebo Members
Tfl	Lebo Member
Tflt	Lebo and Tullock Members
Tft	Tullock Member

MESOZOIC AND PALEOZOIC SEDIMENTARY ROCKS

Kl	LANCE FORMATION
Klm	LANCE FORMATION, FOX HILLS SANDSTONE, MEETEETSE FORMATION, AND BEARPAW AND LEWIS SHALES--On the west side of the Powder River Basin north of T. 45 N., consists of Lance, Fox Hills, and Bearpaw, and, to the south, of Lance, Fox Hills, and Lewis
Kfh	FOX HILLS SANDSTONE
Kfl	FOX HILLS SANDSTONE AND LEWIS SHALE
Kfb	FOX HILLS SANDSTONE AND BEARPAW SHALE
Kle	LEWIS SHALE
Kmv	MESAVERDE FORMATION
Kp	PIERRE SHALE
Kc	CODY SHALE
Kn	NIOBRARA FORMATION

MESOZOIC AND PALEOZOIC SEDIMENTARY ROCKS (continued)

Knc NIOBRARA FORMATION AND CARLILE SHALE
Kcl CARLILE SHALE
Kf FRONTIER FORMATION
Kft FRONTIER FORMATION AND MOWRY AND THERMOPOLIS SHALES
Kgb GREENHORN FORMATION AND BELLE FOURCHE SHALE
Kgbm GREENHORN FORMATION AND BELLE FOURCHE AND MOWRY SHALES
Kmr MOWRY SHALE
Kmt MOWRY AND THERMOPOLIS SHALES
Kns NEWCASTLE SANDSTONE AND SKULL CREEK SHALE
KJ CLOVERLY FORMATION (HARTVILLE UPLIFT) OR INYAN KARA GROUP (BLACK HILLS) AND MORRISON FORMATION
KJs CLOVERLY, MORRISON, AND SUNDANCE FORMATION
KJg CLOVERLY, MORRISON, SUNDANCE, AND GYPSUM SPRING FORMATIONS
Js SUNDANCE FORMATION
Jsg SUNDANCE AND GYPSUM SPRING FORMATIONS
Trc CHUGWATER FORMATION
TrPs SPEARFISH FORMATION
TrPcg CHUGWATER AND GOOSE EGG FORMATIONS
TrPg GOOSE EGG FORMATION
MzPz MESOZOIC AND PALEOZOIC ROCKS--Shown in small areas of complex structure
East flank of Bighorn Mountains--Cloverly, Morrison, Sundance, Gypsum Spring, Chugwater, and Goose Egg Formations (Lower Cretaceous through Permian)
Pmo MINNEKAHTA LIMESTONE AND OPECHE SHALE
Pzr MINNEKAHTA LIMESTONE, OPECHE SHALE, MINNELUSA FORMATION, PAHASAPA AND ENGLEWOOD LIMESTONES, WHITEWOOD DOLOMITE, AND WINNIPEG AND DEADWOOD FORMATIONS--Various combinations
PPc CASPER FORMATION
PPh HARTVILLE FORMATION--Lowermost unit may be Late Mississippian
PPm MINNELUSA FORMATION
PPM CASPER FORMATION AND MADISON LIMESTONE
PM TENSLEEP SANDSTONE AND AMSDEN FORMATION
Mm MADISON LIMESTONE OR GROUP
MD MADISON LIMESTONE AND DARBY FORMATION
MDe PAHASAPA AND ENGLEWOOD LIMESTONES
MDg GUERNSEY FORMATION--Locally includes dolomite and sandstone of Devonian and Cambrian(?) age
MO MADISON LIMESTONE AND BIGHORN DOLOMITE--East side of Bighorn Mountains
Ob BIGHORN DOLOMITE
OC WHITEWOOD DOLOMITE, AND WINNIPEG AND DEADWOOD FORMATIONS
Cr GALLATIN LIMESTONE, GROS VENTRE FORMATION AND EQUIVALENTS, AND FLATHEAD SANDSTONE

METASEDIMENTARY AND METAVOLCANIC ROCKS

Xsv METASEDIMENTARY AND METAVOLCANIC ROCKS
Wgn GRANITE GNEISS
WVsv METASEDIMENTARY AND METAVOLCANIC ROCKS
Wmu Metamorphosed mafic and ultramafic rocks
Ugn OLDEST GNEISS COMPLEX--Overprint pattern indicates area of migmatite related to emplacement of 2,600-Ma granite

PLUTONIC ROCKS

Xgy GRANITIC ROCKS OF 1,700-Ma AGE GROUP
Xgo GRANITIC ROCKS OF 2,000-Ma AGE GROUP
Wg GRANITIC ROCKS OF 2,600-Ma AGE GROUP
WVg PLUTONIC ROCKS

Table 8. Source/criteria arc attribute codes for the land unit coverage.

100 Arcs copied directly from specified coverages

- 101 County boundaries
- 102 Extents for current project
- 103 Land unit coverage for Buffalo Resource Area
- 104 Scoria
- 105 Hydrologic units
- 106 Geology

200 Arcs digitized on-screen with the specified background displays. Arcs have been manually smoothed.

- 201 Scoria
- 202 Geology
- 203 Land cover
- 204 Streams
- 205 30 m shaded relief
- 206 90 m shaded relief
- 207 30 m shaded relief with hatched geology following relief using geology as a guide
- 208 30 m shaded relief with hatched geology following geology primarily
- 209 90 m shaded relief with hatched geology following geology primarily
- 210 30 m shaded relief with hatched vegetation following vegetation primarily
- 212 30 m shaded relief with streams
- 213 30 m slope with hatched geology
- 214 30 m shaded relief with hatched vegetation following relief using vegetation as a guide
- 215 No background
- 216 100 m thematic mapper (4,5,3 (RGB))

300 Arcs digitized from paper maps

- 301 Lusk (1:100,000, folded)
- 302 Devils Tower (1:100,000, folded)
- 303 Sundance (1:100,000, folded)
- 304 Torrington (1:100,000, folded)
- 305 Douglas (1:100,000, folded)